SUSTAINABLE NATURAL RESOURCES MANAGEMENT

Edited by **Abiud Kaswamila**

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Preface

Archaeological evidence suggests that the earliest Neolithic resource users made their decisions on resource use by selecting the best areas for different uses. Resource management strategies have been influenced to varying extents by the nature of the land ever since (Mango, 1996). Conscious land use planning, now worldwide considered to be a panacea of resource use conflicts and a way of increasing productivity, originated during the Greek empire when philosophers like Socrates, Plato and Aristotle encouraged reasoning, logic, invention and scientific ways of solving problems.

On the other hand, past and present efforts on land resources management seem to be inadequate as land degradation, climate change, and demographic pressure continue unabated and land productivity continues to decline at an alarming rate, which is symptomatic of our failure to mitigate the problems. We now channel more than 40% of terrestrial net primary productivity, which is sustenance of all animals and decomposers, to our own needs (Vitousek *et al.*, 1986). Forty-five percent is under cropland and permanent pasture, 36% of Africa, 30% of North America, 35% of South America, 47% of Europe, 25% of former Soviet Union (Woodroffe *et al*., 2005).

The current rate of land resources degradation worldwide is sending a shockwave through mankind. Statistics show that soil erosion and other factors are leading to an irreversible loss of land productivity on more than six million hectares of fertile land a year - about 24% of the inhabited land (Lal, 1993). The values of individual continents range from 12% in North America, 19% in Ocenia, 26% in Europe, 27% in Africa and 31% in Asia (Lal, 1993). Regardless of the methods used for the assessment, it is clear that it is a worldwide problem requiring attention. For example, the Sub-Saharan Africa imports about 10 million tons (60% of demand) of rice annually at a cost of around US $ 6 billion, which is the largest continent's import bill after petroleum (Ngailo & Kaswamila, 2011). In other words, the need for natural resources conservation is as great today as it ever was. Entering the 22nd Century, the challenges to scientists, conservationists, politicians, planners, and decision-makers are to make the world a safe place to live in, today and tomorrow, for the benefit of the present and future generations. Our children and grandchildren should not ask us: why didn't you take action to safeguard our planet?

This book is about finding the best way to manage challenges emanating from accelerating natural resource use. The contributors in this book have vast expertise and experience in natural resources management. All the chapters suggest that sustainable natural resources management can only be achieved through use of system thinking to help us think and learn collectively how to manage complexities and challenges. It provides an integrated approach which finally creates an enabling environment for stakeholders to adopt and benefit from; and adoption of resilience thinking as a paradigm for systematic natural resource management planning process that offers hope of transformational change in the management of socio-ecological systems. It is also evident that technology use such as GIS and remote sensing and modelling have great roles in natural resources management.

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Part 1

Application of Models, Remote Sensing and GIS in Natural Resource Management

1

Fuzzy Image Processing, Analysis and Visualization Methods for Hydro-Dams and Hydro-Sites Surveillance and Monitoring

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1. Introduction

The continuous surveillance, monitoring and operational planning of hydro-dams and hydro-sites is a very important issue, considering the impact of these critical structures on the environment, society, economy and ecology. On one hand, the failure of hydro-dams can dramatically affect the environment and humans; on the other hand, the operating policies must take into account the impact of the water resource exploitation on the hydro-site region and on the regions supplied by the reservoir.

The importance of periodic surveillance and monitoring through both objective measurements and subjective observations is emphasized by existing international standards, which provide the main surveillance and monitoring guidelines for hydro-dams and hydro-sites (CSED, 1983; DSC, 2010). Among other issues, these guidelines clearly state that the visual inspection of the hydro-dams and their surroundings is an important component of the surveillance process, as it aids the decision making process based on direct observations (CSED, 1983, pp. 21-28). Visual inspections complement the other type of data acquired from sensors and transducers placed within the dam body and its surroundings. It is a common practice in hydro-dam surveillance to store the visual observations by human observers in the form of visual observations records. Typically these records regard the state of the reservoir, banks and slopes, concrete structure and downstream valley, and are backed-up by digital image archives of the inspected structures (CSED, 1983; Bradlow *et al.*, 2002).

In respect to the water resource exploitation policy related to the hydro-sites, it is important to develop tools for water resource management evaluation and planning. However these should not be fully automated decision systems, but rather decision support components, to assist the human specialists in establishing the best operation policy. According to the EU Water Framework Directive (2000/60/EC), the water management plan must take into account the natural geographical and hydrological unit rather than the administrative or political boundaries (European Parliament, 2000). This assumes a thorough analysis of the associated complex and heterogeneous data, to perform both the analysis of the current resource management policy and to predict the impact of some management policy on the environment, economy and society. Such a complex task is best performed by a computer decision support system, considering the amount and diversity of the required data/information to be processed. However since the decision on the best water resource management policy to be adopted is to be made by specialists, it is important to provide the decision support system with a human-compliant interface, both for introducing the input information and for displaying the assessment and prediction results in a meaningful and intuitive form to the end-user (this includes, besides numerical data, linguistic and qualitative assessments and, of course, a visual description of the results and recommendations, wherever this is possible). While adopting some existing fuzzy reasoning strategies for the evaluation of the water resource management policy, we mainly emphasize here on our contribution in the enhancement of the results presentation form – particularly on the visual presentation of the future effect of some particular policy, as a geo-typically textured map of the region, using image processing methods to transpose the numerical and qualitative assessment results into a suggestive visual representation.

Most of the solutions presented in this chapter were integrated in a hydro-dam and hydro-site surveillance system, devoted to the monitoring of the Tarnita hydro-site on the Somes River in Transilvania County, Romania. The details of the fuzzy image processing and analysis tools proposed are presented in the remaining of this chapter.

2. Problem formulation

Prior to the introduction of the proposed fuzzy image processing and analysis methods suitable to the visual examination of the concrete hydro-dams surface condition and to the visual rendering of the water resource management policy assessment in a hydro-site region, we consider necessary to give a description of the addressed problems. This should allow the reader to understand and acknowledge the fact that image processing methods may indeed play an important role in the assessment and evaluation of hydro-dams and hydro-sites, although this type of strategy is not so commonly encountered in the field. The following three subsections briefly point the roles of image processing and analysis methods, the role of artificial intelligence approaches and finally present the structure of the system we designed for hydro-dams/hydro-sites monitoring and surveillance, with an emphasize on the role of visual surveillance. Some of the significant references in the scientific literature related to the subject are also outlined.

2.1 The role of image processing and analysis methods in hydro-dams surveillance

In order to enhance the visual observations made by human experts, computer vision techniques may be employed. The approach is to acquire images and then, by the means of specific image processing algorithms, enhance and analyse them. Also, the periodical recording of these images into a database could prove very useful when monitoring the overall condition of the dam walls during time.

Less interest was oriented on incorporating image processing and analysis algorithms to automatically detect, diagnose and predict the behaviour of the dam and the possible faults affecting the structure of the dam. The main interest in processing was to create a 3-D dam map, to be further investigated by the human operator, and even in this step, human intervention is often required. Taking into account the wide variety of computer vision algorithms currently available, is fair to consider that the automation of the visual inspection process of the dam, aiming to detect, diagnose and predict possible faults, can be further increased. Some of the methods presented in this chapter provide solutions to perform specific image processing and analysis tasks in the particular case of infrared and visible images of dam walls.

Bimodal analysis of optical and infrared images is a problem still needed to be tackled with. Few such applications have been reported, mainly in the fields of surveillance, people counting and tracking, robust skin detection (face detection), forest fires detection, or land mines detection (Ollero *et al.*, 1998; O'Conaire *et. al.*, 2006). However, for the diagnosis of dams such works are scarce, although infrared imaging is used extensively in assessing temperature loss, or poor isolations in buildings.

Thermal images can provide information about the scene being scanned which is not available from a visual image. Although much work has been performed for finding various image segmentation techniques in both imaging modalities, little efforts have been made for integration of complementary information extracted from the two imaging modalities.

2.2 The role of artificial intelligence techniques in hydro-sites operation monitoring

The significant development of the information systems puts nowadays its fingerprint on the hydro-sites surveillance and monitoring as well, with a strong emphasize on the design and implementation of intelligent systems to assist the specialists in the above mentioned areas. The artificial intelligence methods play a significant role in the development of systems devoted to dam surveillance and dam monitoring, especially in the form of decision support components and knowledge-based expert systems; among these methods, the well-known fuzzy theory and machine learning solutions (especially neural networks) are commonly employed. Some examples of such artificial intelligence based solutions for hydro-dams and hydro-sites surveillance, monitoring and assessments are briefly mentioned herein. Knowledge-based systems have been employed to assist the diagnosis of seepage from different types of hydro-dams (Asgian *et al.*, 1988; Sieh *et al.*, 1998). Neural networks are also employed in the investigation of seepage under concrete dams founded on rock (Ohnishi & Soliman, 1995) or in the estimation of the dam permeability (Najjar *et al.*, 1996). The joint use of fuzzy mathematics and neural networks is also reported by (Wen *et al.*, 2004), in the development of a bionics model of dam safety monitoring composed of integration control, inference engine, database, model base, graphics base, and input/output modules. Fuzzy logic and artificial neural networks were employed in the inference models building stage, needed to analyze and evaluate the run characteristics of dams.

2.3 Overview of the integrated hydro-site surveillance and monitoring system

Artificial intelligence techniques (including fuzzy logic, fuzzy knowledge based systems, neural networks and other supervised classifiers) have been extensively employed recently in hydro-dam and hydro-sites surveillance applications, as diagnostic tools and policy recommendation tools. However, most existing solutions use measurements acquired from different sensors, and very few of them integrate visual observations obtained from some image analysis modules applied on digital images acquired during hydro-dams and hydro-sites monitoring. In this respect, we describe here a set of image analysis tools developed specifically for the concrete hydro-dams surveillance, which were implemented in the form of an integrated computer vision-based hydro-dam analysis system, capable of providing quantitative, qualitative and linguistic assessments of the concrete surface. The presented visual inspections and expert system components are part of a large hydro-dam and hydro-site surveillance system devoted to the monitoring of the Tarnita hydro-site on the Somes River in Transilvania County, Romania; its block diagram is illustrated in Fig. 1.

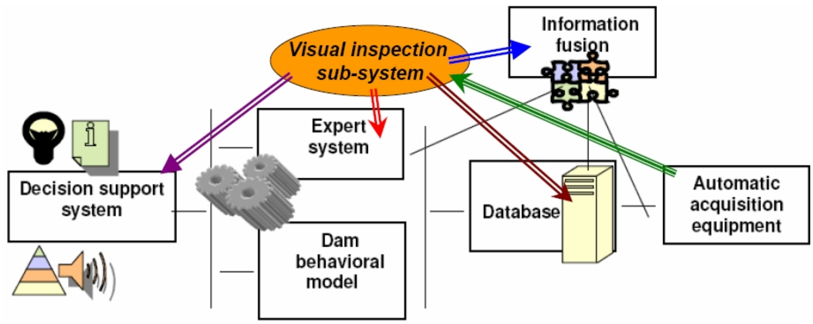

Fig. 1. The integrated system for dam safety decision support, using computer vision techniques and integrating the result of image analysis with the results of other data analysis modules

The automatic acquisition equipments collect multi-sensorial data from the sensors placed in the dam body. These equipments are: automatic acquisition station, capacitive sensor tele-pendulum, optical tele-pendulum, tele-limnimeter, laser telemeter, infrared and visible spectra cameras. All these data are stored into a relational multimodal database. The data fusion algorithms are used to extract relevant information regarding water infiltrations in the dam body, based on infrared and visible spectrum image fusion. Other image processing algorithms are applied to dam wall surface roughness examination, which is also likely to be caused by systematic water infiltrations. The dam models are used for dam behavior prediction and utilize the information stored in the database. The expert system use the human expert knowledge in specific domains and metadata resulted upon their own inference. The decision support system links the user with modeling components, image analysis and fusion modules, expert systems, and the database. Its role is to provide synthetic data in graphical, numerical and linguistic format, which would help the dam surveillance personnel in taking the right decisions regarding interventional measures that will prevent dam degradation and will ensure its functioning in good conditions. Another useful component that may be integrated in the system from Fig. 1 is the one devoted to water resource management policy evaluation and prediction in the hydro-site and the surrounding areas. Most commonly, such components are built using fuzzy rule base systems/fuzzy logic systems, as this mathematical framework is very suitable to handle both exact and approximate (qualitative or linguistic) knowledge, and this mixture of information representation is often encountered in management evaluation systems. Our contribution in terms of a visually enhanced representation of the water resource management policy assessment results is also presented in the end of this chapter.

3. Downstream concrete surface evaluation of hydro-dams by image analysis

Visual inspection is a key element in dam monitoring process, allowing decisions to be made about dam behavior, based on direct observations. Visual inspections complement the data analysis process concerning different sensors and transducers placed within the dam body and it's surroundings, and the observations are filled in a standardized form describing the inspections results about: reservoir, banks and slopes, concrete structure, downstream valley. These records hold, for every feature observed, the procedures utilized during inspection as well as significant images illustrating the observations. Hence, once digital images of the inspected structure are available, a series of aspects are suitable for image analysis: detection and quantification of calcite deposits, detection of areas with humidity, evaluation of concrete surface of the wall in order to reveal structure faults or cracks, and so on.

It is a known fact that most cracks in dam walls have calcite exuding from them, indicating that moisture traversed the cracks (Abare, 2006). As water seeps through cracks, it leaves calcite deposits at the surface adjacent to the cracks. If the area between concrete layer is porous, the movement of water through them would accelerate the leaching action. Seepage samples may be collected, analyzed and compared to reservoir water to help determine whether soluble minerals pose a structural safety problem (Craft *et al*., 2007). Seepage could be estimated by estimating the volume of water required to precipitate the measured volumes of calcite in the unsaturated zone (Marshall *et al*., 2003). Besides these techniques, we will show that computer vision can also help detect and assess the calcite deposits and humidity of the concrete dam walls.

The deterioration of the concrete walls may also be an important concern as it may indicate the degradation of the downstream side, and to give an estimate of this type of degradation we proposed a solution to examine the surface roughness (Gordan *et al*., 2008). Besides an accurate identification of such deteriorations, we show that computer vision techniques help in providing a quantitative and qualitative description of the extent of the deterioration. It is important to note that all the results of the proposed computer vision techniques can easily be transcribed to the visual observation record and offer the advantage of an intuitive and natural presentation to the end user.

In terms of downstream concrete surface evaluation of dams, we propose the following:

1. A modified fuzzy c-means segmentation method (semi-supervised through the use of support vector regression) for the detection, localization and quantification of calcite areas in the plots of the downstream concrete surface of a hydro-dam. The difficulty of this image segmentation problem comes from the large variability of calcite deposits appearance, uneven distribution of data, variations of the concrete appearance depending on the acquisition conditions and devices. The proposed solution outperforms the classical segmentation algorithms in terms of accuracy (96% as compared to 91% with the classical fuzzy c-means).

2. Furthermore, since less severe infiltrations may only be visible in the infrared spectrum, we also propose an integration of infrared image analysis with the visible image analysis, using a late decision fusion to integrate the results of the two image analysis modules. The fusion is thought to take into account the spatial and temporal correlation of the two types of images of the same hydro-dam downstream surface. This approach should yield more reliable results in terms of infiltration assessment.

These algorithms and techniques are described in detail in the following sub-sections. The images to be processed are drawn from the multimodal database, which holds digital images of concrete dam walls. Such an image is illustrated in Fig. 2. These are cropped to elementary units, called sub-plots. Each sub-plot image is identified by information that allows later identification and association with the real scene (the identification data is: horizontal, vertical and plot number). Thus, it is easier to extract images from the same sub-plot taken at different dates or in different modalities (e.g. visible or infrared spectrum).

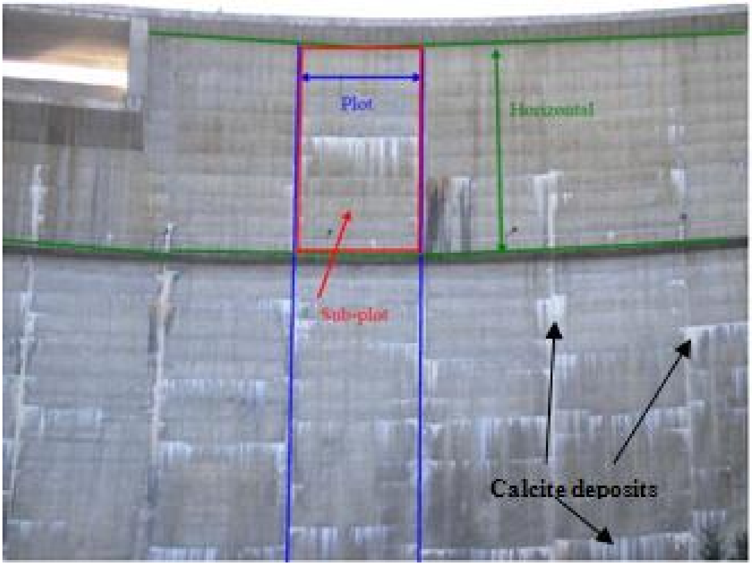

Fig. 2. Image sample at the input of the visual inspection module

3.1 Infiltration assessment by the analysis of calcite deposits using fuzzy segmentation

Calcite patches are good indicators of significant and time persistent water infiltrations; they are most likely to occur as being transported by the water infiltrations from concrete in the case of a repetitive water infiltration in a certain area of the dam. Therefore the problem of identifying the calcite formations on the concrete wall through an algorithm able to provide maximum accuracy despite the variability of appearance of calcite deposits, the variable lighting conditions on the portion of the wall, without knowing in advance if calcite is or is not present in the current image, or in what amount, must be tackled. These aspects make the calcite identification and assessment a rather difficult image analysis problem: the significant variability of the calcite appearance makes almost impossible the derivation of a calcite appearance model to be used in the identification; model-free approaches seem more suitable, trying to identify natural pixels clusters, followed by an interpretation of the clustering results to identify if any represents calcite or not.

A rather powerful approach to non-supervised image segmentation by pixel clustering is the fuzzy c-means algorithm (FCM) (Dunn, 1973; Bezdek, 1981). Many variations of the FCM algorithm were successfully applied in image segmentation. Actually, various forms of fuzzy clustering have been employed to different image segmentation tasks. In (Chamorro *et al.*, 2003), the segmentation of color images is achieved by a nested hierarchy of fuzzy partitions, based on a measure of color similarity. Starting from an initial fuzzy segmentation, a hierarchical approach, based on a similarity relation between regions, is employed to obtain a nested hierarchy of regions at different precision levels. Type 2 fuzzy sets are employed in (Clairet *et al.*, 2006), for color images segmentation, to allow a better modeling of the uncertainty. A modified fuzzy c-means segmentation scheme with spatial constraints is introduced in (Hafiane *et al.*, 2005), in the form of a two step segmentation method. Another fuzzy clustering method, with no constraints on the number of clusters, aiming to segment an image in homogeneous regions, is presented in (Das *et al.*, 2006).

The solution that we proposed for the segmentation of the calcite deposits on the concrete hydro-dam walls images is more application-targeted (and it worth noting that it may be also generalized to other application-specific segmentation tasks, as it provides a framework to incorporate a-priori knowledge in the fuzzy c-means cost function). Details on this approach may also be found in (Dancea *et al.*, 2010). The calcite identification on the concrete dam wall can be treated as a pixel classification problem. As there is no prior knowledge regarding the shape of the calcite deposits, the spatial constraints are not really helpful in the segmentation; the colors of the pixels are the only relevant features to consider. An important fact to consider however is the amount of the calcite deposits on each dam wall image, which is significantly smaller than the entire wall region. If we build a data set to be clustered comprising all the pixels in the currently analyzed image, classified into calcite and non-calcite samples, this set will be highly unbalanced among the classes of interest, and this is an unfavorable situation in a classification task, being prone to more errors in the poor represented class. This situation can be partially overcame by defining the classification data as the set of distinct colors in the concrete dam wall image, each color being included only once. From the several possible color spaces, we prefer the natural Red Green Blue (RGB) representation, as it is just as suitable as others for Euclidian distance based classifiers; thus each sample (corresponding to a color from the image) is represented by a vector $\mathbf{x} = [R \quad G \quad B]^T$. The image to be segmented is considered to be a sub-plot image of a dam wall, as shown in Fig. 2. Therefore the current data set is formed by the colors in this sub-plot color image, $X_C = \{\mathbf{x}_i \mid i = 1,2,...,N_C\}$, where N_C denotes the number of distinct colors in the current image. Our goal is to classify/cluster the data in X_C in one of two possible classes of interest: calcite deposit – denoted by C_C, and not calcite – denoted here by $\overline{C}_C$. Although this is actually nothing else but a binary classification problem, trying to solve it by an unsupervised fuzzy c-means clustering of the data in only two classes will risk to be unable to group all the colors corresponding to the class “anything else but calcite", since their variance is too large. Therefore a larger number of classes than two only will be needed in the initial clustering, one per dominant color. An examination of the sub-plots shows that generally two dominant colors are present in the non-calcite sub-plot areas: a grayish like color corresponding to the concrete and a brown-black color corresponding to organic deposits. Thus a 3-class clustering should be performed, with two classes for the $\overline{C}_C$ dataset and one the calcite, C_C.

The fuzzy c-means algorithm (Bezdek, 1981) is a very efficient clustering procedure when the number of clusters is known a-priori, aiming to find natural fuzzy groupings of the data according to their similarity in respect to a selected distance metric. In the end of an iterative objective function minimization process, the optimal class centers and membership degrees of the data to be clustered are found, with the optimality defined as the minimization of the classification uncertainty among the data in the classes. However a good clustering result is only achieved if the amount of data in each cluster is relatively balanced; otherwise the expected fuzzy centroid of the class with fewest data can be rather different than the real centroid of the class. This is mainly due to the fact that although the distance between the data and the resulting class center is large (leading to a large cost in the objective function), if the number of these terms is negligible in comparison to the size of the data set, it will contribute insignificantly to the total cost. While we already tried to avoid this case by taking all the colors in the sub-plot only once, this caution might still not be enough to guarantee a balanced data set. Therefore, furthermore, we propose to apply a modified objective function in the fuzzy c-means clustering, which assigns a higher penalty to the misclassification of the expected calcite pixels colors, that is, of the lighter colors in the data set X_C. We should mention here that, although the number of pixels colors corresponding to the organic deposits (brown-black, that means – dark-most) is also much smaller than of the grayish pixels, we are not concerned about their misclassification here, as in the worse case, the color of a brown-dark pixel is closer to a grayish pixel than to a calcite one, and then the misclassified data for the organic deposits can never appear in the calcite class C_C.

Let us denote by C – the number of classes to which the N_C samples x from the set X_C are to be assigned in some membership degree; in our case, C=3. The membership degrees of the data to the classes is stored in a matrix $U\left[C \times N_C\right]$, where the u_{ji} element, j=1,...,C and i=1,...,N_C, represents the membership degree of the vector $\mathbf{x}_i$ to the class j. Each line in U is the discrete representation of the fuzzy set corresponding to a data class. The C fuzzy sets are constrained to form a fuzzy partition of the data set X_C. Starting from any initial fuzzy partition of the data set to be fuzzy classified X_C, the algorithm aims to optimize the partition in the sense of minimizing the uncertainty regarding the membership of every data x_i, i=1,…,N_C, to each of the classes. In the proposed weighted fuzzy c-means algorithm, we introduce a set of class-specific scalar positive weights w_j, j=1,…,C, to assign different relative importance to the distances of the data in X_C to each of the classes centers. With these weights, we build a fuzzy c-means weighted objective function in the form:

$$J_{w,m}(U,V) = \sum_{i=1}^{N_C} \sum_{j=1}^{C} u_{ji}^{m} \cdot w_j \cdot d^2\left(\mathbf{x}_i, \mathbf{v}_j\right) \tag{1}$$

whose minimization is done iteratively, as in the standard fuzzy c-means algorithm, using the following equations for the computation of the fuzzy class centers v_j and for the fuzzy membership degrees u_{ji}:

$$\mathbf{v}_j = \frac{\sum_{i=1}^{N_C} u_{ji}\mathbf{x}_i}{\sum_{i=1}^{N_C} u_{ji}};\ u_{ji} = \left(\sum_{l=1}^{C} \left(\frac{w_j \cdot d\left(\mathbf{x}_i, \mathbf{v}_j\right)^2}{w_l \cdot d\left(\mathbf{x}_i, \mathbf{v}_l\right)^2} \right)^{\frac{1}{m-1}} \right)^{-1} \tag{2}$$

In the expressions above, V is the set of the class centers, $V=\{v_1,..,v_C\}$, $v_j \in \Re^3$; m is a parameter controlling the shape of the resulting clusters (typically m=2); $d(\cdot,\cdot)$ is a distance norm in the RGB space between any two vectors. A common choice for d, used in our approach as well, is the Euclidian distance. The iterative process ends when the change in either U or V is under a certain tolerance (error) (in theory, arbitrarily small).

The three weights w_1, w_2 and w_3 are estimated roughly using the shape of the histogram of the brightness component of the segmented image; the shape descriptor which proves useful for our case is the skew of the histogram, as it provides a numerical measure of the distribution of the samples to the left and right of their mean. Using solely the brightness and not the color is sufficient for our goal, as our concern is to be able to "differentiate" the light-most class (which accounts for calcite as explained above) from the other two classes. Therefore we give default fixed weights to the non-calcite classes and tune just the calcite class weight as indicated by the histogram's skew. Considering an N sample set formed by the brightness values of the pixels in the currently analyzed sub-plot, $\{y_1, y_2, \ldots, y_N\}$, the sample's skew γ can be estimated as the ratio between the third central moment of the sample and the cube of the sample's standard deviation:

$$\gamma = \frac{\mu_3}{\mu_2^{\frac{3}{2}}} = \frac{\frac{1}{N}\sum_{i=1}^{N}\left(y_i - \bar{y}\right)^3}{\left(\frac{1}{N}\sum_{i=1}^{N}\left(y_i - \bar{y}\right)^2\right)^{\frac{3}{2}}},\ \bar{y} = \frac{1}{N}\sum_{i=1}^{N} y_i. \tag{3}$$

For a uni-modal histogram having the gray levels are evenly distributed around the mode, the skew is close to zero. If more darker pixels than brighter pixels are present in the examined image, the skew γ will be negative. On the opposite, if the brighter pixels are dominant and outnumber the darker ones, γ will be positive. Based on these considerations, we can perform the following adjustment of the calcite class weight depending on the skew γ (assuming the other two classes have fixed weights). If γ is positive (i.e., the number of light pixels accounted for calcite is large enough), there is no need to enhance the importance of the calcite class in respect to the other two, and we can set the calcite weight equal to the other classes. If γ is negative or near zero, it indicates the areas of calcite are rather small as compared to the examined surface, so the calcite class weight should be increased. Intuitively, the more negative γ is, the larger the weight assigned to the calcite class should be.

Note that although there is no a-priori association of the class index j, j=1,2 or 3, and the brightness of the colors in the class, we always know that the fuzzy class with light most colors is the fuzzy class whose center is the lightest, and this class will be considered to correspond to the calcite (if any):

$$C_C = C_k \left| k = \underset{j=1,2,3}{\operatorname{argmax}} \left(\begin{bmatrix} 0.299 & 0.587 & 0.114 \end{bmatrix} \cdot \mathbf{v}_j \right) \right. . \tag{4}$$

To be able to effectively employ the above considerations into our algorithm, a numerical mapping between the range of values γ and the range of weights of the light-most, i.e. calcite pixels class, must be obtained. Denoting our target weight by w_k, with k given by Eq. (4), we search for the mapping $w_k(\gamma)$ that best fits a set of training data, obtained by manually tuning the value w_k on a set of statistically significant dam wall images (with enough variability in appearance, to cover as many practical cases as possible). A set of 15 images of several sub-plots, with different aspect, under different lighting conditions and different amounts of calcite (from none to very severe) have been selected and manually analyzed to optimize the calcite class' weight for an accurate calcite identification. The pairs formed by the skew values and the best manually selected weight values w_k have been collected, and an interpolation procedure based on support vector regression (SVR) has been applied on this training set to completely define in an automatic fashion the computation of the weight w_k. We assumed the other two classes' weights "fixed" to 1.

The reason for using SVR in the interpolation step is its proven good performance when only a relatively sparse set of data points is available. Based on Vapnik and Chervonenkis's statistical learning theory (Vapnik, 1998), support vector learning principle allows handling successfully difficult cases, with better precision and recall than other learning methods. This is mainly due to the structural risk minimization principle implemented by SVMs. SVMs were initially "built" for classification and later extended to the regression issue – SVR – by introducing a loss function (Scholkoph *et al.*, 1998; Platt, 2000). Starting from an input data set, represented by a vector x, the SVM learns the functional dependency between input and output, represented in the form of a scalar-valued function f(x). The expression of the regression function provided as a result of learning by an SVM is:

$$f(\mathbf{x}) = \sum_{i=1}^{L} \left(\alpha_i - \alpha_i^* \right) K(\mathbf{x}, \mathbf{x}_i), \tag{5}$$

where L denotes the total number of training data, α_i and α^*_i are their associated Lagrange multipliers, and the function $K(x,x_i)$ represents a kernel function used for mapping the input data in a higher dimensional input space. In our experiments, a polynomial kernel of degree 7 was considered. According to the observed skew values in our images, its range was limited to [-2;2]. The range of values for the weights w_k is chosen to be [1;10]. The resulting mapping $w_k(\gamma)$, after applying SVR on the training set is represented in Fig. 3.

Experiments were run on a set of 15 large, high resolution images, from which we chose 60 manually segmented sub-plots (as illustrated in Fig.2). The performance of the proposed segmentation method was assessed on the test set of 60 sub-plots, using a previously manually drawn ground truth (on which the calcite regions were manually marked). The difference between the ground truth segmentation and the segmentation result of our algorithm allows us to assess the segmentation error, the false positives and the false negatives for the calcite class. The segmentation error for the calcite class achieved with our method, expressed as the average percentage of misclassified pixels in the test set for the total 60 sub-plots, is 4.19%, whereas for the standard fuzzy c-means algorithm is 9.64%(more than double). Some segmentation results are illustrated in Fig. 4.

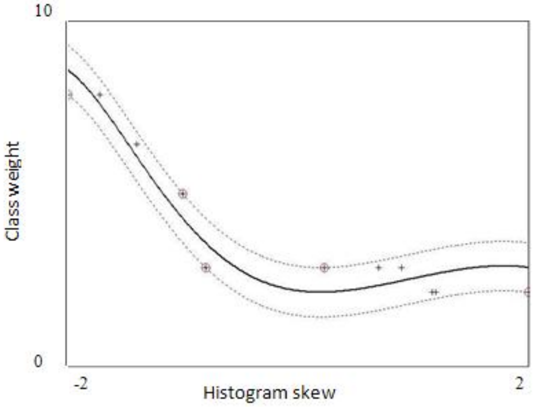

Fig. 3. Skew to class weight mapping

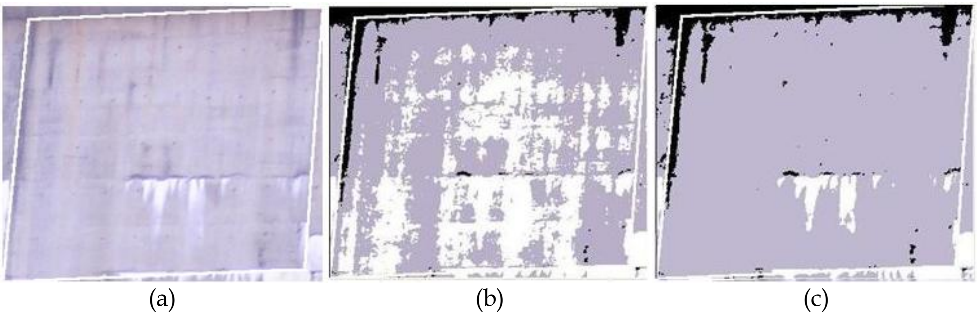

Fig. 4. Example of the calcite segmentation for a sub-plot: (a) the original (not segmented) sub-plot image; (b) the fuzzy c-means segmentation result; (c) the proposed weighted fuzzy c-means segmentation result.

Despite the good performance of this segmentation procedure in the localization of calcite, one must take into account that less severe infiltrations may not produce significant calcite deposits yet, and may only be visible in the infrared spectrum. Therefore the integration of infrared image analysis results with the visible image analysis results, using a late decision fusion, can bring more valuable information in the infiltration assessment. The fusion is thought to take into account the spatial and temporal correlation of the two types of images of the same hydro-dam downstream surface. This approach is presented in the following sub-section.

3.2 Bimodal infiltration assessment through the integration of infrared and visible information

The block diagram of the bimodal fusion based approach for water infiltration assessment is schematically illustrated in Figure 5. Many of the operations involved in the acquisition and low level processing of the visible spectrum and infrared spectrum images are done independently (in a parallel processing fashion). Apart from the acquisition, these operations include: visible spectrum and infrared spectrum images delimitation at plot level (as shown in Figure 2); visible and infrared image segmentation and infiltration severity degree mapping in the two imaging modalities for the quantitative description of water infiltration information. On the output of the corresponding stages, we simultaneously have the two water infiltration degrees maps decided by the two modalities, to integrate these decisions by a simple fusion process.

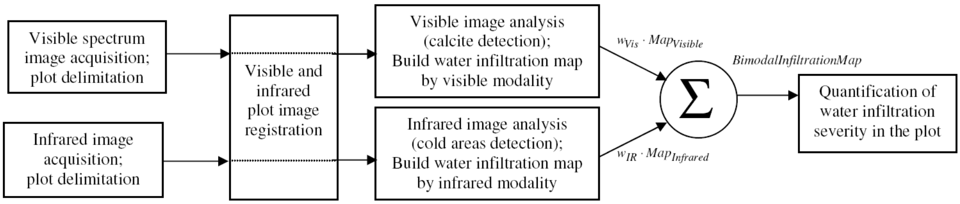

Fig. 5. Block diagram of the proposed method for infiltration assessment within the dam body

After the acquisition step, a registered pair of sub-plot images is available to be taken from the visual inspections database, each corresponding to the same element. The processing described in the following refers to such an aligned pair. For the infrared image acquisition we used a thermal camera with temperature coding capabilities (providing a thermal map of the corresponding dam wall area). We refer the image of the currently analysed plot in the visible spectrum as "the visible image" and the image of the same plot in the infrared domain will be referred as "the infrared image" and we assumed they are pixel-level registered by scaling and translation compensation. An example of such a registered (visible, infrared) image pair for a plot of the dam wall is shown in Figure 6.

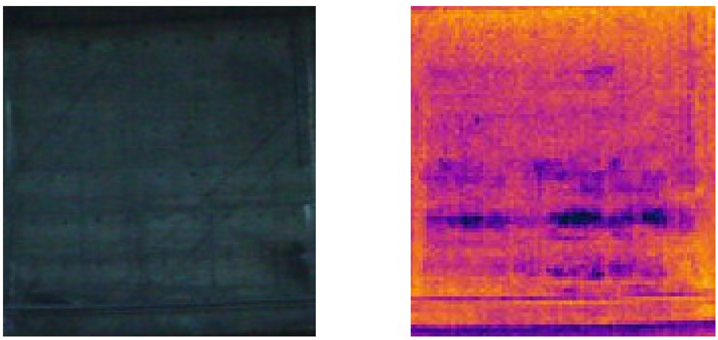

Fig. 6. A pair of images for a hydro-dam wall plot acquired in the two modalities: visible spectrum modality (left) and infrared modality (right)

The visible image analysis and segmentation for calcite detection was already presented in the previous sub-section. For the bi-modal analysis we discuss here, a further step is required: the creation of the ″water infiltration map″ in the visible domain. This map must actually illustrate the severity of the water infiltration, but this severity is (as discussed priorly) correlated to the ″amount″ or severity of the calcite deposits: in the areas where the water infiltrated on a long period of time, the calcite deposits will appear brighter, as the calcite layer is thicker. We map the severity degree of water infiltration to an intensity range {0,1,...,255}, with 0 for the lack of any infiltration to 255 for maximum severity infiltration. Accordingly we can convert the segmented ″visible image″ (with calcite areas identified as explained in the previous sub-section) into a visible infiltration severity degree map. To do so, we consider that the brightness component Y is a sufficiently good indicator of the "whiteness" of the calcite – therefore, of the severity of the infiltration also. We represent in matrix form the brightness component of the ″visible image″ from the current plot pair by $I_Y[H\times W]$, with elements in the range {0,1,...,255}. Let us consider the segmented plot image, with the pixels assigned to one of the two classes: calcite or non-calcite, represented as a binary matrix as well, $S_{Vis}[H\times W]$. With these notations we build the water infiltration map of the visible image as the matrix $Map_{Visible}[H\times W]$, according to the following expression:

$$Map_{Visible} = \frac{\mathbf{S}_{Vis}(i,j)\cdot \mathbf{I}_Y(i,j)\cdot 255}{Y_{Max,Calcite}} \quad (6)$$

where $Y_{Max,Calcite}$ is the maximum possible intensity for calcite areas, derived from a set of training images corresponding to calcite patches on the hydro-dam wall. An example of a water infiltration map for the „visible image" in the left side of Figure 6 is illustrated in Figure 7.

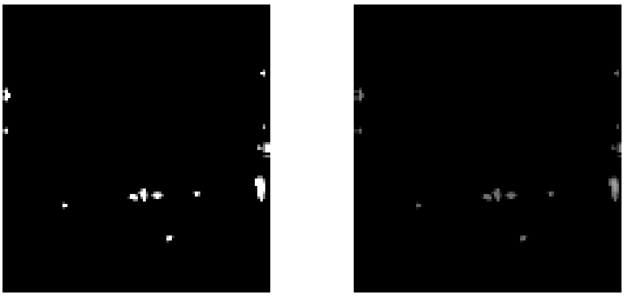

Fig. 7. Plot image segmentation result in the visible domain: Calcite against not calcite segmented image (left) and infiltration severity degree map (right)

On the other hand, the infrared image analysis and segmentation aims to identify the cold areas, to produce a water infiltration map from the infrared image of the plot. It is known that, at least in the spring/summer, when the ambient temperature is rather high, the areas of the plot with water infiltrations appear colder in the plot's thermal map. The more significant the water infiltration is, the colder is the local part of the plot, thus the lower the temperature on the plot's thermal map. However we can expect that in such areas little evidence of calcite will be identified in the visible image, since the calcite is likely to occur in the region below the wet areas. This gives reason to believe that the two information sources can favourably complement each other. Since in the case of the thermal maps we always have available exactly the color-temperature conversion scale, we can use this scale and a-priori knowledge about the numerical range related to the qualifier „cold" to obtain the accurate identification of the water infiltration areas. An example of the selected scale portion, as considered to represent water infiltrations in our application (the severity of the infiltrations is stronger as the color is closer to violet and dark violet than to red), is illustrated in Figure 8. The red color is considered to be already not cold at all, whereas the very dark violet is considered to be the coldest possible. The simplest way to convert this color scale into a scalar scale in the range {0,1,...,255}, with 0 for the minimum coldness and 255 for the maximum coldness, is to use the negative of the red color component intensity of the scale image, as shown in Figure 8.

Fig. 8. The cold temperature part of the infrared scale: Original (left); its red component (right)

The segmentation process of the infrared image of the plot into cold areas and not cold areas is done pixel wise, based on the pixel color. The RGB space is uniformly quantized with only 4 bits per color component to guarantee the color match of the "infrared image" pixels with the infrared scale. We also gather and denote by SCold the set of the quantized color intensities in the RGB representation of the IR scale corresponding to cold from Figure 8, and simply assign the pixels in the infrared image of the plot the label 1 if their quantized color is found in SCold, and 0 otherwise. As a result, we obtain the segmented infrared image of the plot into cold against not cold areas, described by the matrix S_{IR} [H×W].

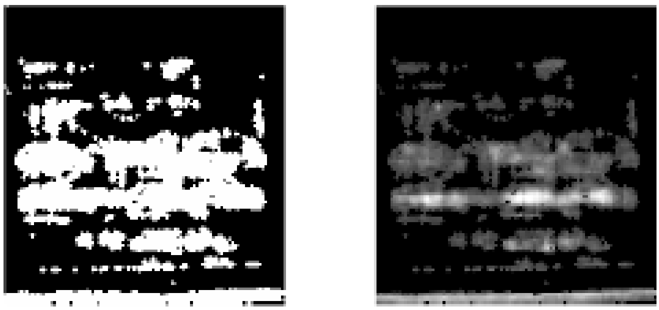

Fig. 9. Plot image segmentation result in the infrared domain: Cold against not cold segmented image (left) and infiltration severity degree map (right)

Afterwards, we build the water infiltration severity degree map in the infrared domain – similar to the one in the visible domain. However in the infrared case, we consider as infiltration severity degree indicator – the negative of the red color component in each pixel position previously classified as cold, as discussed earlier. Let us denote by $Map_{Infrared}$[H×W] – the severity degree map of the water infiltration in the infrared modality, represented in the range {0,1,...,255}. The values in this matrix are computed as:

$$\mathrm{Map}_{\mathrm{Infrared}}(i,j) = S_{IR}(i,j)\cdot\left(255 - I_{R,IR}(i,j)\right) \tag{7}$$

where $I_{R,IR}[H\times W]$ represents the intensity of the red component in the infrared image of the current plot.

The segmentation result in "cold" and "not cold" areas for the infrared plot image given in Figure 6, where the segmented image is presented as a binary image (black – "not cold", white – "cold"), and its associated water infiltration severity degree map, are given in Fig. 9.

The final processing step is the bimodal fusion of visible and infrared water infiltration severity information. We use the two individual information sources already provided by the independent image processing and analysis stages: the visible and infrared image processing, to obtain the overall assessment and quantification of the water infiltration amount in the currently analysed plot. Several fusion schemes are available, varying from very simple (pixel-based) to complex ones, to perform the information integration from two or more modalities; the most used in particular for visible and infrared bimodal information fusion can be found in (Yin and Malcolm, 2000; O'Conaire *et al.*, 2006). Among these, one of the simplest schemes is by weighted averaging of the decisions given by each modality alone at pixel level, provided that the visible and infrared image registration was previously performed. Let us denote the decision about the plausibility of presence of a certain event in the spatial position (i,j) in the visible spectrum modality by $d_{Vis}(i,j)$ and the decision about the plausibility of presence of the same event in the spatial position (i,j) in the infrared modality by $d_{IR}(i,j)$. We also consider the weights (confidences) assigned to each modality denoted by w_{Vis} and w_{IR}, chosen to satisfy the constraints: $w_{Vis} \in (0;1)$; $w_{IR} \in (0;1)$; $w_{Vis} + w_{IR} = 1$. The confidences w_{Vis} and w_{IR} assigned to each modality are derived based on expert's knowledge about the relative significance of each modality in assessing the severity of the water infiltration. The presence of calcite shows persistant, longer duration water infiltration in the plot, thus its weight should be higher than the infrared's information source weight. We chose as confidence values in our application: w_{Vis}=0.65 and w_{IR}=0.35. As information sources to be weighted aggregated, we use the individual water infiltration severity degrees maps, Map_{Vis} and Map_{IR}. The overall water infiltration severity degree map, represented as an intensity image in the range $\{0,1,\cdots,255\}$, with 255 – maximum infiltration severity, is obtained as:

$$\mathrm{InfMap}(i,j) = w_{Vis}\cdot \mathrm{Map}_{Vis}(i,j) + w_{IR}\cdot \mathrm{Map}_{IR}(i,j). \tag{8}$$

An example of the resulting water infiltration severity degree map after bimodal image fusion, for the plot presented in Fig. 6, is given in Fig. 10. Then this overall decision map can be used to compute quantitative descriptors of the water infiltration amount and local severity on the plot. Examples of such simple quantitative descriptors are given in (Gordan *et al.*, 2007): the percentage of the water infiltration area from the total plot area; the maximum local severity degree of water infiltration, assessed as the accumulated severity of the infiltration reported to the total area exhibiting infiltration.

In order to test this method we used the same multi-modal database containing images acquired from Tarnita dam, near Cluj-Napoca. We selected 5 pairs of plots acquired in both modalities (visible and infrared). As shown earlier in this section, a ground truth for visible image segmentation into calcite areas and non-calcite areas can be easily obtained, and the same – a ground truth for pixel classification into cold areas for the infrared images. Thus we can assess the functionality of these processing stages very accurately. However, this is not the case for the assessment of water infiltrations severity, which in general can only be subjectively estimated by human observers. Therefore we can only roughly compare the results provided by our algorithm, converted to subjective scales, to subjective (human) evaluation of the water infiltrations based on the visible and infrared plot image evaluation. These comparative results for the 5 pairs of plots are presented in Table 1. The only difference from the human expert's opinion is in the 4th line in Table 1, for a plot exhibiting water infiltration in a very small area, in respect to the local severity of the water infiltration: although the numerical results show a large local value, the human expert identifies it as not significant, and this could be explained by the overall assessment done by the human expert, with almost no attention to local details when the water infiltration region size is not significant. The segmentation results, both for the visible and infrared plot images show in all cases good accuracy.

Although we employ here one of the most simple fusion schemes, we can see how the use of the two modalities can lead to better results than the analysis of each imaging modality alone. Also, the implementation of the joint analysis of visible and infrared images into the visual inspections module we described at the beginning of this chapter, has the advantage of providing numerical estimates of the extension of the water infiltrations and severity of the water infiltrations in the plots, reducing the risk of human observer subjectivity and image display quality.

Plot pair Number	Water Infiltration Area	Infiltration Severity	Infiltration amount (subjective)	Infiltration severity (subjective)
1	32.05%	81%	Medium/Large	Severe
2	23.63%	58%	Medium	Moderate
3	24.46%	64.7%	Medium/Small	Moderate
4	2.4%	72%	Almost none	Reduced
5	43.7%	78%	Large	Severe

Table 1. Quantitative results of our algorithm against subjective human expert's opinion

4. Assessment of the water resources management policy in a hydro-site region

As the hydro-dams reservoirs are also the main water supply resources for the geographical region, the assessment of the water management policy in the operation of the hydro-dam in respect to various economical and environmental factors is also an issue of significant interest. In this respect, we propose and implement a fuzzy decision support component to help in assessing the water resource management. Whereas the evaluation strategy itself is inspired by the work of (Zhou & Huang, 2007), employing a hierarchical process analysis strategy with qualitative reasoning, the presentation of the assessment results is novel, as we aim to display the evaluation not only in numerical and linguistic form, but also in a visual form. The originality of the presented solution consists in the presentation of the water resource management evaluation "grading" in the form of a geotypical textured map of the region, where the natural texture changes according to the evaluation result for a specific category and according to the qualifier assigned to the management policy (varying from worst to very good). Therefore, in this sub-section we primarily emphasize on this visualization enhanced results presentation part. The interested reader may find more details of the implementation of the tool in (Gordan *et al.*, 2010).

To achieve a meaningful graphical representation, we propose to employ fuzzy alpha-blending, image morphology and fuzzy image inpainting algorithms, which allow the production of high quality and meaningful geotypically textured maps of the hydro-site region. This allows the user to get multiple clues on the results of the water resource management evaluation, and have a stronger impact than the numerical assessment alone. The advancements and new application tracks of image processing algorithms and display devices provide the means for advanced graphical representations to be easily integrated in decision support software tools. These components are not so widely employed in the existing systems, but some implementations exist, as e.g. the integrated information management and simulation system combining WebGIS, database and hydrological model in (Shaomin *et al.*, 2009) – which integrates a flood simulator and visually presents the flooded areas; or, the GIS based integrated system, which also incorporates hydrological analysis and cascade hydroelectric station dispatching functions, with powerful visualization tools (Shi *et al.*, 2006).

The case of water resource management assessment may significantly benefit from a visualization module provided in the form of a geotypically textured map of the evaluated region. This can easily embed digital maps and natural images specific to the site, combined with specifically designed rendering tools. The fuzzy evaluation process results should drive the rendering of the appropriate textures on the digital map of the region.

Adopting the terminology in (Zhou & Huang, 2007), the factors involved in the assessment of the water resource management are called indexes. Each index represents a relevant attribute in the water resource management evaluation, and it must allow either a numerical or a qualitative description. During the system's setup, a weight must be assigned to each index, showing its relevance in the assessment of the water resource management. The weights may vary depending on the available water resources in the region and on the overall regional conditions. As the water resource management may impact several facets of life (the natural resources of the region, the ecology and the environment, the society and the economy of the region), a group of indexes is defined for each category individually. This will allow an independent evaluation of the water resource management policy's impact on each category. So far we implemented the decision support component only for the category of natural resources. This implies the definition of the appropriate set of relevant indexes for the natural resources, influenced by the water management policy.

As shown in the literature, five indexes are most relevant for the natural resources category in the framework of water resource management: the total water resources; the water resources per capita; the utilization rate of the water resources; the annual rainfall; the water shortage rate (Zhou & Huang, 2007). These five indexes are grouped into the index layer of the component. Based on their current values and on the management evaluation procedure, the quality of the water resource management policy in respect to the natural resources preservation is expressed in terms of five fuzzy qualifiers: Worst, Bad, Moderate, Good and Best, grouped in the output layer of the component – known as the "condition layer".

The decision support component for the evaluation of water resource management policy in respect to the natural resources preservation must include a so-called training phase, in which the specialist helps defining the fuzzy sets membership functions associated to each index and each linguistic qualifier in a set Q={*Worst*, *Bad*, *Moderate*, *Good*, *Best*} (in respect to the specific category), and the weights of the indexes in the evaluation. Then, in the evaluation phase, the current values of the indexes – let us consider them given in the form of a vector x - are provided to the input of the system. Based on the values in x, the evaluation algorithm computes a membership degrees vector u[1×5], showing the confidence in assigning the currently examined water management policy to the fuzzy categories from Q, in the *Worst* to *Best* order. The vector u of confidence degrees in the suitability of each linguistic qualifier for the current water management policy in respect to the resource category is also used in the visual rendering sub-system.

The visual rendering of the evaluation results is achieved as follows. Assume that, for the current geographical region, we have its geographical map, with some manual marking of the interest categories, as e.g. the one shown in Figure 10, for the Somes river basin in Romania, corresponding to a good operation situation. Starting from this image, we would like to generate two geotypically textured images: one corresponding to the *Worst* resource management case, in which the exploitation was not proper, and one corresponding to the *Best* resource management case, with a very good water resource management policy.

In principle, the *Best* case geotypically textured map simply needs some texture synthesis applied on the image in Figure 10, using suitable natural textures for the forest, water, rock – and the approach we employed to generate the natural looking textured map was a modified version of the exemplar-based image inpainting approach of (Criminisi *et al.*, 2003). An example of inpainting the forest region over the map from Figure 10 is shown in Figure 11. However, in the *Worst* case image, it would be good to also apply some additional processing; a suitable choice is to perform some morphological operations – as: erosion of the rivers; dilation of the mountain area, to enhance the visual effect of a very bad policy, prior to inpainting the map with the suitable textures.

Once the two geotypically textured images corresponding to the two extreme water resource management qualifiers are created, we would like to display any intermediate results as given by our assessment fuzzy system. Consider the two images represented as three-dimensional matrices I_{Worst} and I_{Best}, of size $W_I \times H_I \times 3$ each, where W_I is the image width, H_I - the image height, and 3 is the number of color components per image. We already have available the degrees in which the management of the water resources can be considered *Worst* (the value of the first component from the vector u), *Bad* (the value of the second component from u), *Moderate* (the value of the third component from u), *Good* (the value of the fourth component from u) and *Best* (the value of the last component from u). The only thing to be done is to combine the two images I_{Worst} and I_{Best} to obtain the correct visualization as a new image I_{Result}, according to:

$$I_{Result} = \alpha \cdot I_{Best} + (1-\alpha) \cdot I_{Worst}, \tag{9}$$

where α is some blending factor ranging between 0 and 1, generated at the output of a Takagi-Sugeno fuzzy system, with the following configuration:

1. Input fuzzy sets: the five linguistic qualifiers (*Worst*, *Bad*, *Moderate*, *Good*, *Best*)
2. Output fuzzy sets: five singletons – one for each reference value α, corresponding to the reference case of a *Worst*, *Bad*, *Moderate*, *Good* or *Best* management. These values were chosen intuitively and empirically to: $A_{Worst}=A_1=0$; $A_{Bad}=A_2=0.2$; $A_{Moderate}=A_3=0.5$; $A_{Good}=A_4=0.8$; $A_{Best}=A_5=1$
3. Rule base: five fuzzy rules, associating each qualifier to an output singleton, in the form: R_k: If *Qualifier* is q then $\alpha=A_k$, $k=1,2,\ldots,5$; $q = \{$ *Worst*, *Bad*, *Moderate*, *Good*, *Best*$\}$.

As the result of the Takagi-Sugeno inference, the output value for the blending factor α is given by: $\alpha = \frac{\sum_{k=1}^{5} u_k \cdot A_k}{\sum_{k=1}^{5} u_k}$.

The results of the assessment are illustrated for two different cases of indexes' values: close to best management and between bad and moderate, but not worst management, as shown in Figure 12. The results are compliant to the observer's expectations.

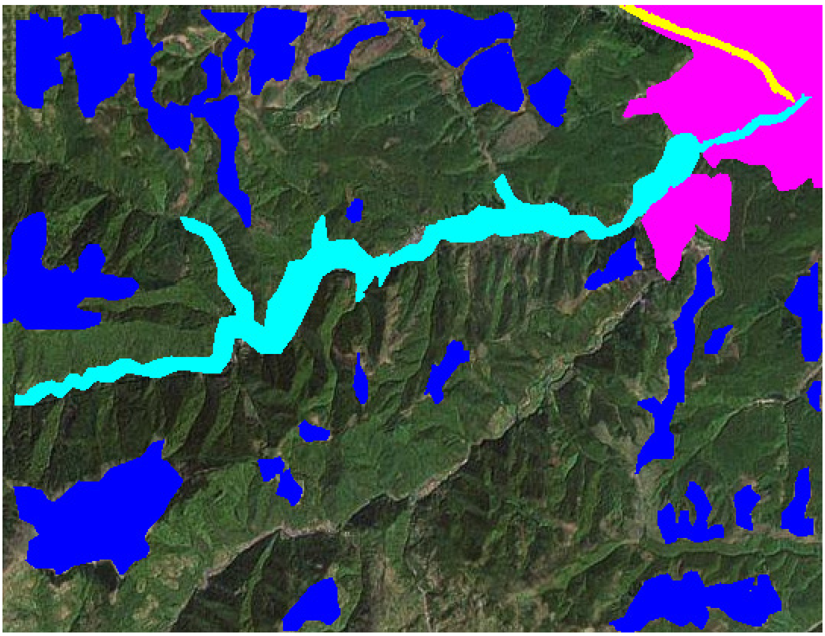

Fig. 10. Illustration of the Somes River Basin marked map, to be further processed in visualization purposes

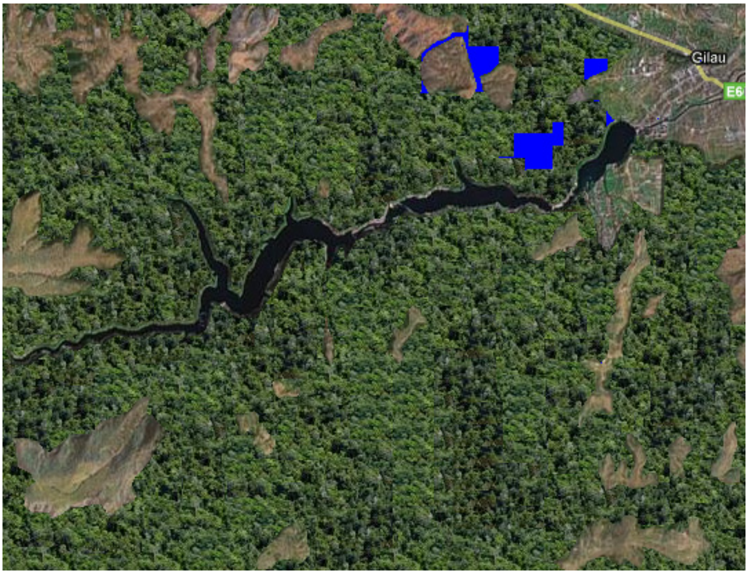

Fig. 11. Illustration of an inpainting result for the forest region with a natural texture, corresponding to the best resource management case

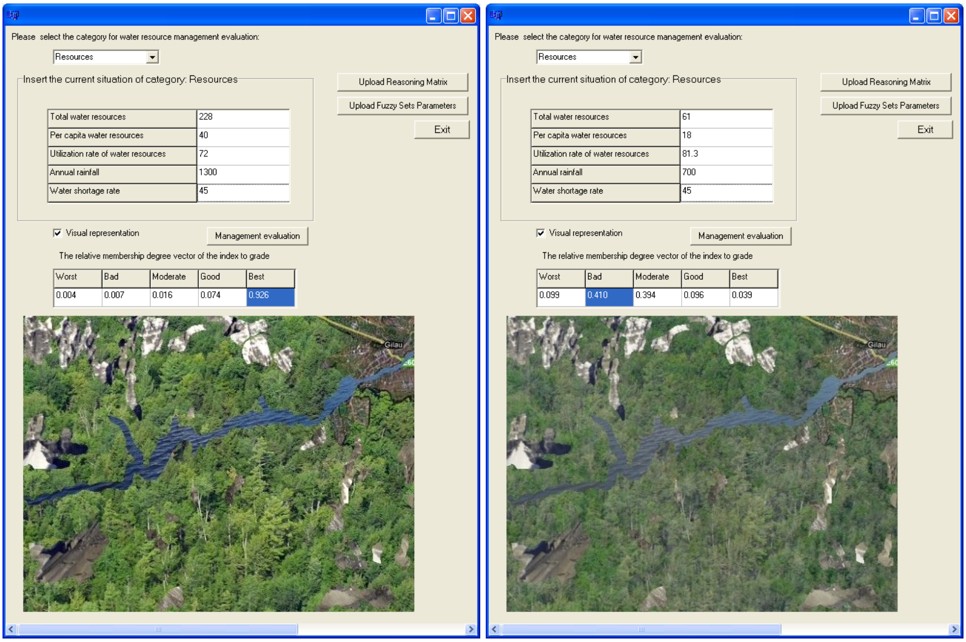

Fig. 12. Illustration of the water resource management policy assessment for the *Resource* category for: The *Best* management case (confidence 0.926) (left); The *Bad* to *Moderate* management case (confidence 0.41 for *Bad* and 0.39 to *Moderate*) (right)

5. Conclusion

This chapter aimed to present a series of novel fuzzy image processing methods and algorithms implemented in the rather general framework of hydro-dams and hydro-sites surveillance, monitoring and assessments, emphasizing on their theoretical motivation and results. Most of these methods have been employed in a hydro-dam and hydro-site integrated system for the safety decision support of these critical structures, thus the results are verified on real image data. Future work still needs to be done in this field, as the integration of the presented fuzzy image analysis algorithms (especially for the visible and infrared modalities) is just in its beginning; other imaging modalities as e.g. sonar, as well as the underwater examination of the hydro-dam structure would be of significant interest. Furthermore, the integration of the hydro-sites surveillance systems with water resource management policy assessment in the region operated by the dam reservoirs is another challenging issue.

6. Acknowledgment

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2

Upstream Landscape Dynamics of US National Parks with Implications for Water Quality and Watershed Management

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1. Introduction

The mission of the United States (US) National Park Service (NPS) is to "conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (NPS, 1916). NPS currently manages 397 parks covering about 358,200 km^2, or approximately 4% of all US states and territories. The National Park system includes approximately 300 parks that are considered to contain significant natural resources. These parks are key components of a larger network of protected areas that anchor the conservation of natural resources in the US. They also afford direct protection for a number of important and defining resources in the US, including 421 species of threatened or endangered plants and animals, nearly two-thirds of native fishes in the 50 states (Lawrence *et al*., 2011), the highest point in North America (Mt. McKinley in Denali National Park, 6,194 m), the longest cave system in the world (Mammoth Cave National Park with more than 587 mapped km of caves), the country's deepest lake (Crater Lake in Crater Lake National Park, 589 m), the lowest terrestrial point in the western hemisphere (Badwater Basin in Death Valley National Park at 86 m below sea level), and – within these extremes – many other natural resources that are significant at local, regional, and national scales.

While protected areas are foundational to a strong natural resource conservation network, ecologists have long recognized that virtually all parks are too small to be self-sustaining ecosystems, and activities outside park boundaries can profoundly impact park resources (Newmark, 1985; US General Accounting Office, 1994; Parks & Harcourt, 2002; Wiersma *et al*., 2004; Hansen & DeFries, 2007; Hansen *et al*., 2011). Chief among these activities is the intensification of land use and the appropriation of ecological services. Land use intensification leads to the conversion of natural habitat, which generally results in an overall loss of habitat, fragmentation of remaining natural areas, increases in edge zones, changes in the runoff of water, sediments, and nutrients, and follow-on modification of physical and ecological processes in terrestrial and aquatic ecosystems. Depending on the location, extent, and magnitude of these anthropogenic changes, the effects may propagate over very large areas and have important consequences for resource management in protected areas.

While the NPS mission is to protect all natural resources, water is perhaps the most universally important resource to parks and to protected areas worldwide. Provision of fresh water is a key ecosystem service provided by many parks, and wetlands and riparian habitats are often biological 'hot spots' that support disproportionately high levels of biodiversity (Stein *et al.*, 2000; Scott *et al.*, 2001). Because fresh water resources are so important to parks, the focus of this chapter is on landscape-scale factors that affect water resources and associated values. Flowing water directly connects water resources inside and outside park boundaries. Landscape-scale activities beyond park boundaries can particularly affect water resources and the ability of parks to manage and protect these resources. A means to identify and quantify imposing threats is thus important to designing and implementing effective park management strategies.

To manage an extensive network of protected areas like the NPS system of parks, there is a clear need to assess the system-wide context and status of parks relative to their goals (Scott *et al.*, 2001; Svancara *et al.*, 2005). Results from broad-scale analyses can identify patterns and trends that may be undetectable at the individual unit scale, and provide guidance for changes in regional or national-level policy. Scott *et al.*, (2001), for example, noted that US protected areas (parks, refuges, etc) disproportionately represent lands characterized by high elevation, low productivity, and low rainfall – the places that are cold, dry, and barren. Areas in highly productive river valleys – the location of many biodiversity hot spots – were disproportionately under-represented in the network of protected areas. The widespread availability of broad-coverage, geospatial data on environmental conditions and landscape attributes has facilitated new and sophisticated analyses of the geographical context and anthropogenic impacts to terrestrial, freshwater, coastal, and marine ecosystems at regional, national, and global scales (Sanderson *et al*., 2002; Halpern *et al*., 2007, 2008; Leu *et al*., 2008; Woolmer *et al*., 2008; Lawrence *et al*., 2011).

While a few studies have measured and assessed the landscape characteristics of US National Parks (Scott *et al*., 2001; Svancara *et al*., 2009; Davis & Hansen, in press; Wade *et al*., 2011), these efforts focused on the broader landscape context or specific components of the landscape, rather than watersheds, even though water is one of the most defining resources for parks and other protected areas (Dixon & Sherman, 1991; Hawkins *et al*., 2003). To our knowledge, only Lawrence *et al*., (2011) have rigorously evaluated system-wide the upstream landscape dynamics of US National Parks, specifically from the perspective of maintaining protection for freshwater fish diversity. They used broad-scale datasets to assess both threats to the use of parks as 'freshwater protected areas' and the potential capacity to manage activities in the contributing watersheds. Based on a relatively simple set of analyses, but involving computationally intensive operations, they were able to identify a subset of parks that could serve as the foundation for a system that would likely preserve a large proportion of US freshwater fish.

To guide the analyses in this chapter, we asked a series of questions:

1. Based on established ecological principles and landscape-scale data, what is the general context of park upstream watersheds?

2. Which major landscape factors explain most among-park variation in upstream watershed context?
3. What can we infer about the condition of park freshwater resources, and how do these vary geographically?
4. What are the major challenges and opportunities for managing park upstream watersheds?

We first describe the ecological foundation and general approach to evaluating park upstream watersheds. We proceed to describe the selection of variables and data sources used in the analyses, and briefly review the ecological basis for including those variables. We then outline the analytical techniques and criteria for including or omitting parks from the study. The final sections of the chapter present the results of our watershed and water quality analyses, and our interpretation of these results. We conclude with a summary of our principal findings and recommendations for future research.

2. Assessing watershed condition

2.1 Ecological foundation

Figure 1 illustrates our overall conceptual model for assessing parks at a landscape scale. The model acknowledges key anthropogenic drivers (or stressors), important attributes of the natural landscape, and contextual elements that affect conservation and management actions. Analyses that consider these elements can evaluate geospatially explicit broad-scale vulnerabilities and opportunities for conservation and management. Our model is founded on more comprehensive analyses by Hansen & DeFries, (2007) of the mechanisms that link land use intensification to the resources within protected areas.

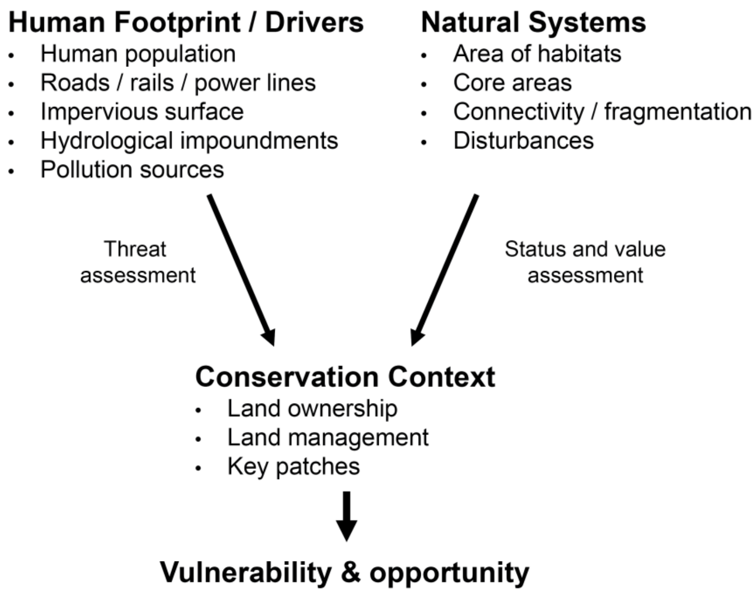


Fig. 1. Conceptual model used as a basis for landscape-scale assessment of parks.

Broad-scale data generally available include the human drivers represented in the model, and all of these drivers are well known to influence biodiversity and other park resources. Natural systems can be characterized in many ways, and the types of attributes in Figure 1 are a subset of important attributes that can be used to assess the context and condition of natural systems. The conservation context provides information that may be essential to decisions on land management. Svancara *et al.*, (2009) conducted a national-level analysis by county of the conservation context of US national parks and refuges, and they discuss the use of this information to achieve conservation goals.

2.2 Landscape variables and data sources

Using the conceptual model as an overarching framework, we approached our analyses within the broader goals of the NPS landscape dynamics monitoring project, NPScape (http://science.nature.nps.gov/im/monitor/npscape). NPScape is designed to support landscape-scale monitoring conducted by the NPS Inventory and Monitoring Program (Fancy *et al.*, 2009). Key NPScape objectives are to provide: a coherent conceptual and analytical framework for conducting landscape-scale analyses and evaluations that can inform decisions; Geographic Information System (GIS) data and maps at broad spatial scales that transcend the bounds of park-level data; well-documented methods founded on strong science that are readily repeatable and extensible with local data; and, assistance to parks in interpreting results.

In support of these objectives, NPScape produces and delivers a suite of landscape-scale datasets, methods, GIS scripts and tools, maps, and guidance reports to approximately 300 natural resource parks in the NPS system. Results from NPScape are intended to inform resource management and planning at multiple scales. Because the overarching goal of NPScape is to deliver information to parks across the entire NPS system, inputs are limited to data sources that cover broad spatial extents (i.e., regional to national).

NPScape incorporates a large number of datasets that can be roughly categorized into 'base layers' and 'variables'. Base layers are such things as topography, jurisdictional boundaries, hydrography, and the other geospatial data that are relatively static and that generally serve as covariates or provide a geopolitical context. The NPScape variables considered here address two major elements in our conceptual model: stressors and conservation context.

Important stressors are evaluated by measures of population, housing, roads, and impervious surface (a category of land cover). Conservation context was evaluated from the percentage of land in a protected status, and potential management partnerships from the number of different agency or institutional owners of conservation lands. The NPScape data sources and variables used in our analyses are described in Tables 1 and 2. Although NPScape includes a variety of other metrics related to natural land cover and landscape pattern, we did not use these in our national-level assessment because they require a more in-depth analysis at ecoregional scales. Our present focus on human drivers and conservation context is designed to serve as a foundation to these future studies.

Measure	Source data	Years	Spatial resolution	Reference
Population	US Census Bureau	2000	Census block groups	US Census Bureau, 2001; NPS, 2010a
Housing	Spatially Explicit Regional Growth Model (SERGoM)	2010	100 m cells	Theobald, 2005; NPS, 2010b
Roads	Environmental Systems Research Institute (ESRI)	Varies, up to 2005	Varies	ESRI, 2010; NPS, 2010c
Land cover	National Land Cover Data (NLCD)	2006	30 m cells	NPS, 2010d; Fry *et al.*, 2011
Conservation status	Protected Areas Database of the US (PAD-US)	Varies, up to 2010	Varies	NPS, 2011a; USGS Gap Analysis Program, 2011

Table 1. NPScape data sources used to compute the landscape variables (listed in Table 2).

Measure	Variable	Units	Comments
Population	Population density	count/km²	Based on population totals
Housing	Housing density	# units/km²	Based on mid-points of rural, exurban, suburban , and urban
	Rural housing	% area	0-6 units/km²
	Exurban housing	% area	7-145 units/km²
	Suburban housing	% area	146-1,234 units/km²
	Urban housing	% area	>1,234 units/km²
	Commercial/industrial	% area	Business – non-residential
Roads	Weighted road density	km/km²	Highway weighted by a factor of 3, interstates by 10
Land cover	Impervious surface	%, area weighted	Anthropogenic sources only
	Developed	% area	Anderson Level I
	Developed open space	% area	Anderson Level II
	Low intensity development	% area	Anderson Level II
	Medium intensity development	% area	Anderson Level II
	High intensity development	% area	Anderson Level II
	Agriculture	% area	Anderson Level I
	Cultivated crops	% area	Anderson Level II
	Hay/pasture	% area	Anderson Level II
Conservation status	Protected	% area	Based on Gap Analysis Program (GAP) codes 1 and 2
	Landowner density	count/km²	All owners of conservation lands, including NGO & private

Table 2. NPScape variables used in the present analyses.

In addition to NPScape variables, we included the percentage of each watershed in private ownership (derived from USGS Gap Analysis Program, 2011), and we obtained data on river impoundments and nitrogen (N) deposition. The US National Inventory of Dams database now contains more than 83,000 records of significant impoundments in US states and territories (US Army Corps of Engineers, 2010). These impoundments have dramatically altered hydrological flow regimes, sedimentation processes, inhibited or prevented biological migrations and other movements, and influenced virtually every ecological process in some catchments (Ward & Stanford, 1979). Following Sabo *et al*., (2010) and Lawrence *et al*., (2011) we used the density of impoundments (count/km^2) in the contributing watershed as an indicator of river fragmentation. A future refinement to our analyses is to include additional information on the characteristics of dams and their effects on aquatic resources. For example, watersheds in the eastern US tend to have a higher density of dams than western watersheds, but because the size of dams varies, the storage capacity as a portion of annual flow is nearly the same in the east and west (Sabo *et al*., 2010). Thus western rivers generally have fewer but larger dams, so fragmentation is greater in the east but dams in the west alter hydrological dynamics more.

Anthropogenic activities now contribute more nitrogen (N) to the global cycle than all natural sources combined (Vitousek, 1997). Nitrogen is, or was, a key limiting element in many aquatic systems, but these limits are now exceeded in many parks (Baron *et al*., 2011). Baron *et al*., (2011) reviewed studies on N limitations in North American lakes. These studies revealed a consistent pattern of historical N limitations, especially in nutrient-poor environments typical of high elevations, and undisturbed temperate and boreal forests. Broad patterns of response to atmospheric N deposition further supported assertions that the majority of lakes in the Northern Hemisphere may have been N-limited prior to increased N deposition from anthropogenic sources. Atmospheric deposition of N has sufficiently altered the balance of N and Phosphorous (P) so that P limitations are now more commonly observed in North American lakes. These results emphasize the need to incorporate aspects of global change in broad-scale studies. Our analyses of N deposition are based on measurement of inorganic N wet deposition from the National Atmospheric Deposition Program (NADP), corrected for topographic precipitation differences using PRISM (Parameter-elevation Regressions on Independent Slopes Model) climate data as described in Baron *et al*., (2011). These data underestimate total N deposition because they do not account for dry deposition. We did not attempt to account for terrestrial runoff or other N inputs.

2.3 Upstream watersheds and the headwater index

Watersheds that are either upstream or downstream with respect to a particular management unit may be calculated from Digital Elevation Models (DEMs) using GIS (Djokic & Ye, 1999). The park upstream watersheds considered here were calculated by NPScape using this basic methodology (NPS, 2011b). However, rather than relying on source DEM data, NPScape was able to take advantage of published DEM-derived datasets that serve as standardized pre-processed inputs to watershed calculations: the National Hydrology Dataset Plus (NHD Plus, 2010) vector flowlines, NHD Plus flow accumulation rasters, and NHD Plus flow direction rasters. In addition to these inputs, our calculations required NPS current administrative vector boundaries (NPS, 2011c) to determine pour points from the flowlines.

We used these four datasets (flowlines, flow accumulation grids, flow direction grids, and park boundaries) as inputs to the NPScape ArcGIS watershed toolbox (NPS, 2011b) to generate upstream catchments for all 261 natural resource parks in the contiguous US. Most parks had multiple upstream catchments originating from different sets of pour points around park boundaries. We dissolved catchment boundaries by park to derive final park upstream watersheds. Importantly, watersheds were computed with respect to the entire network of parks, meaning that upstream catchments were delineated based on the most proximate park in the NPS system. This decision was made in order to evaluate the landscape factors that relate directly to each park. Furthermore, because many parks occur in major river systems, it helped ensure that upstream watersheds were small enough to be practical for park management considerations, yet still ecologically relevant when considered in a larger NPS context.

From these outputs we applied a series of quality-control filters to eliminate park upstream watersheds with obvious inaccuracies (NPS, 2011b). We eliminated park watersheds where there were obvious errors with the source NHD Plus data, parks that were too small in relation to the spatial resolution and mapping accuracy of the source data, and parks that were in areas with complex hydrography (e.g., coastal, marine). These filters eliminated 110 of the 261 natural resource parks in the contiguous US, leaving a total of 151 focal parks and their contributing upstream watersheds that were considered in the analyses (Fig. 2).

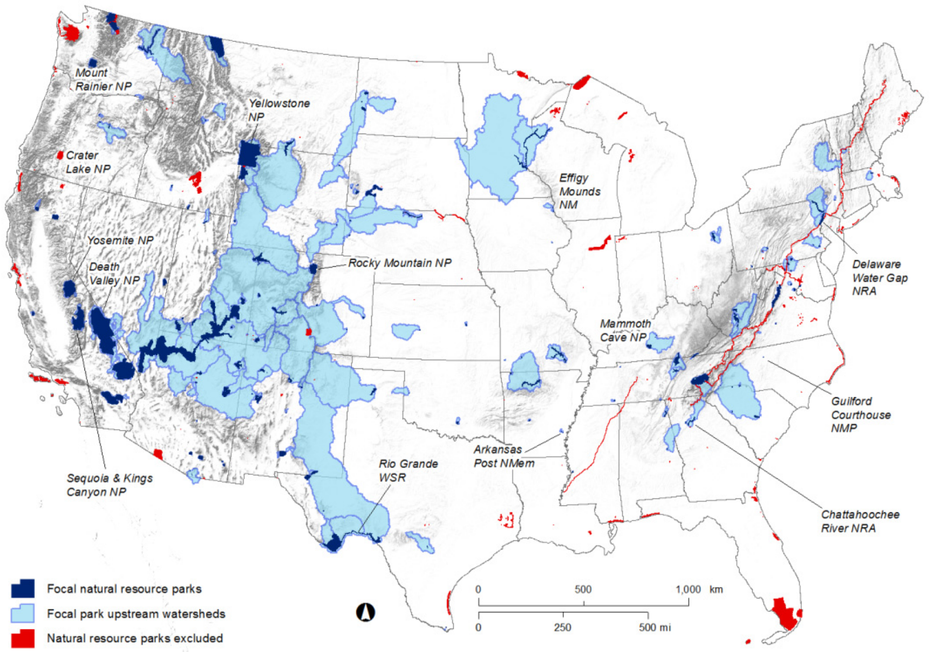


Fig. 2. Focal parks and upstream watersheds considered in the present analyses. Labelled parks are referred to in the text. NP = National Park, NRA = National Recreation Area, NMP = National Military Park, NM = National Monument, NMem = National Memorial, WSR = Wild and Scenic River.

We used the park boundaries and upstream watersheds to compute a geometric index of the degree to which a park includes its own headwaters. The headwater index was calculated by intersecting each park with its upstream watershed, then dividing that area by the total area of the upstream watershed. The resulting proportion ranged from zero (i.e., all upstream areas flowing into the park) to one (i.e., all upstream areas flowing out of the park).

2.4 Water quality variables and data sources

We derived estimates of water quality inside focal parks from two sources: the NPS Hydrographic and Impairment Statistics (HIS) database (http://nature.nps.gov/water/his/) and the Environmental Protection Agency (EPA) Storage and Retrieval System (STORET; EPA, 2011). The HIS provided data for each park on the total length of waterway (rivers, streams, canals, etc), as well as the total length of 'impaired' waterway identified by states according to the federal Clean Water Act sections 303(d) and 305(b). We used these two variables to estimate the percentage of total waterway in each focal park that was impaired (impairment data were not available for the Rio Grande Wild and Scenic River). In addition, we downloaded water chemistry data from STORET for the area within a 3 km buffer outside park boundaries for all parks in this study, restricting the data to observations from 1995-present, and to samples from rivers/streams, lakes, and reservoirs. Although STORET provides access to a very large number of chemical and biological variables, we restricted our analyses to acid neutralizing capacity, ammonia-nitrogen as N, dissolved oxygen, nitrogen-nitrate, pH, phosphate-phosphorus as P, dissolved solids, and specific conductance.

2.5 Analyses

We used a combination of univariate and multivariate methods to address our starting questions. Where possible we tried to emphasize univariate approaches, which are methodologically more intuitive and straightforward to interpret in a management context. However, because we considered a large number of landscape variables, we also needed a means to simplify analysis of the many correlated variables. To do so, we used principal component analysis (PCA) to identify broad orthogonal groupings of variables that explained most variation in park upstream watershed context. All statistical analyses were performed in R (R Development Core Team, 2011). Corresponding maps of select results were produced in ArcMap (ESRI, 2011); all maps are Albers equal area conic, NAD83.

The PCA was conducted using the landscape variables in Table 2, plus mean N deposition and dam density. Owing to non-normal distributions of the raw variables, arcsine transformations were first applied to all percentage (proportion) variables, and log transformations were used on all density variables. We excluded the headwater index from the PCA because we wanted to evaluate the major factors responsible for landscape-level change and management response (i.e., human drivers and conservation context) in park upstream watersheds, irrespective of their relatively static spatial geometries. We used the loadings of each transformed variable on principal components 1 and 2 (PC1, PC2) to interpret the meaning of each axis. Park-specific scores on PC1 and PC2 were then evaluated both geographically and in relation to the headwater index. For the latter, we regressed each principal component (dependent variable) on the arcsine transformed headwater index in order to explore the residuals and characterize the management potentials of non-headwater parks.

For water quality, we used Pearson's product moment correlation to characterize the association between the percentage of park waterway impaired (arcsine transformed) and PC1. We limited this correlation to PC1 because it explained the majority of landscape variation among park upstream watersheds. Meanwhile, an initial examination of STORET water quality data revealed implausible observations (outliers) for some variables. To reduce the effect of outliers in our analyses, we calculated the 95th percentile of the distribution for each variable and then multiplied this value by 3 (P3) and by 20 (P20). We removed all observations with values greater than P20. For observations with values between P3 and P20, we changed the observed value to the value of P3 (i.e., we truncated the distribution to ± P3). To obtain a single value for each variable and each park, we first calculated the median value of the observation for each site within a specific park area of analysis. We then calculated the mean of the site-specific medians for that area. We used linear regression with the park-specific mean values and our predictor variables (i.e., PC1, PC2, and a subset of NPScape variables in Table 2) to explore relationships between water quality and landscape attributes. After filtering the STORET data for date, location, and outliers, our analyses were based on usable data for 29-117 parks (mean = 78).

3. Results and discussion

3.1 What is the general context of park upstream watersheds?

Park upstream watersheds are potentially threatened by a number of landscape-level factors related to park-watershed geometry, housing development, habitat conversion and resource extraction, and N deposition (Fig. 3). Of the 151 park upstream watersheds considered, 81% have more than 50% of their watersheds extending beyond park boundaries, 77% have less than 50% area formally protected, 61% have greater than 10% rural development, and 37% have values for N deposition exceeding 3.5 kg N ha^{-1} yr^{-1} – a conservative critical load for most parts of the contiguous US (Baron *et al.*, 2011). Taken in combination, these numbers suggest that most parks do not directly control most of their watersheds, and that both physical and chemical stressors originating beyond park boundaries will likely affect water resources inside park boundaries. However, despite these challenges, it is equally noteworthy that park upstream watersheds are relatively unthreatened by converted land cover, including high-intensity human land use (Fig. 3). Of the 151 park upstream watersheds, just 12% are greater than 50% converted land cover, 17% are greater than 10% developed land cover, and 30% are greater than 10% agricultural land cover.

Several of these patterns merit further discussion. The low-level of protection afforded most park upstream watersheds is due in large part to the working definition of 'protected'. We consider parks and other areas 'protected' if they have permanent protection from conversion of natural land cover and a mandated management plan to maintain a primarily natural state. This definition follows from the US Geological Survey (USGS) Gap Analysis Program (GAP), which uses a series of four codes to rank areas based on their level of protection (USGS Gap Analysis Program, 2011). Our definition is based on GAP status codes 1 and 2 and includes most parks and all wilderness areas, but it excludes most lands managed by the Bureau of Land Management (BLM) and US Forest Service (USFS). These two Federal agencies combined manage approximately 1.8 million km^2, which irrespective of their use and reduced level of protection represent significant areas for natural resource conservation. We revisit this subject below in the context of watershed management opportunities for parks (Section 3.4).

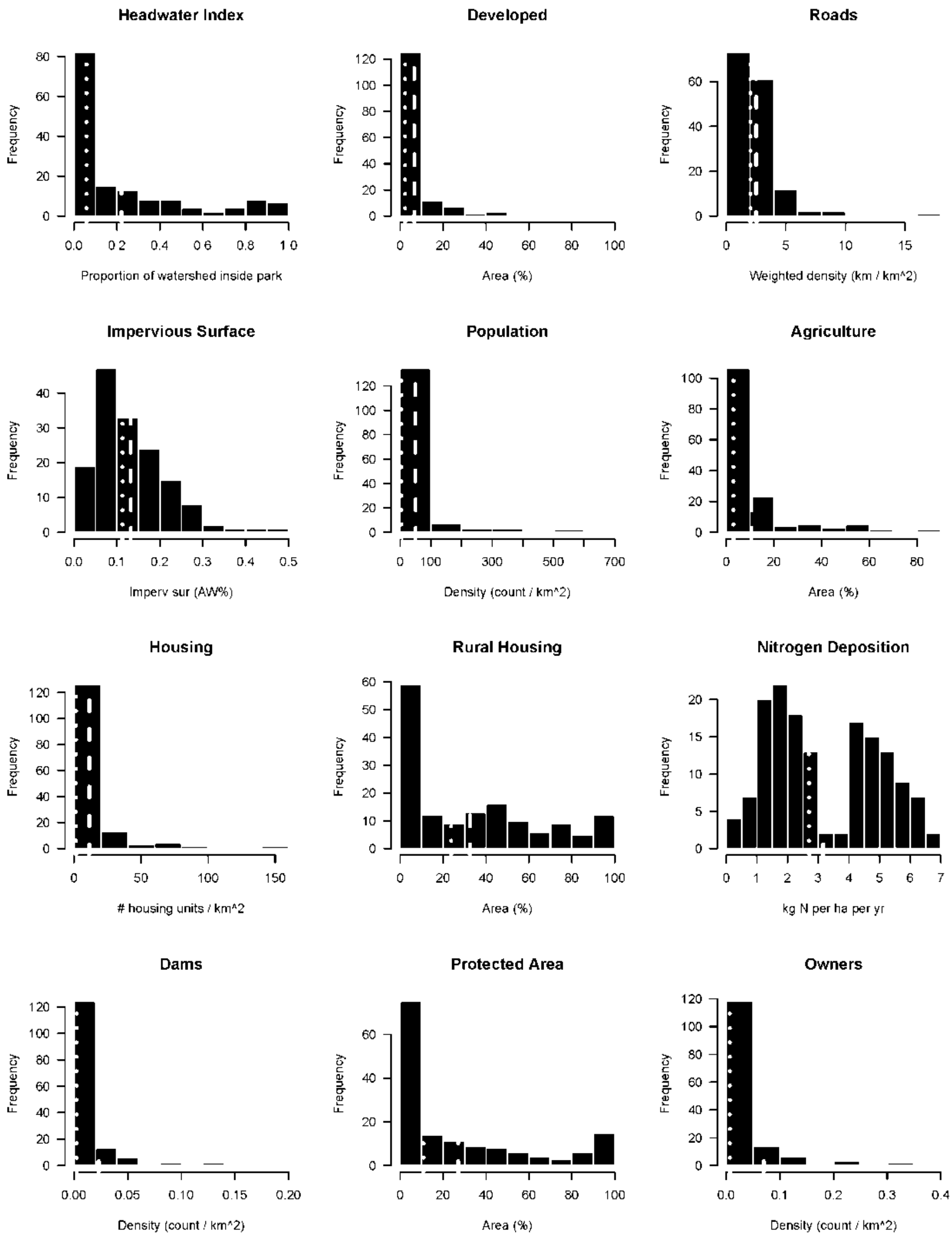


Fig. 3. Univariate distributions of select landscape variables for upstream contributing watersheds of 151 National Parks in the contiguous US. Dashed lines show means; dotted lines show medians.

Park upstream watersheds are bimodally distributed with respect to N deposition (Fig. 3). This bimodality is strongly influenced by a combination of longitude and elevation. Based on critical loads from Baron *et al.*, (2011), all park upstream watersheds in the east exceed the critical load of 3.5 kg N ha^{-1} yr^{-1} reported for the northeast; Yosemite, Sequoia, and Kings Canyon National Parks all exceed the critical load of 1.5 kg N ha^{-1} yr^{-1} reported for the Sierra Nevada; and, all parks in the Central Rockies exceed the critical load of 1.0 kg N ha^{-1} yr^{-1} reported for the Rocky Mountains (Fig. 4). Hence, despite geographic variation in N deposition across parks in the contiguous US, most park upstream watersheds considered here have values exceeding critical loads for their respective geographies. Future work is needed to incorporate more detailed geographic estimates of critical loads for N deposition.

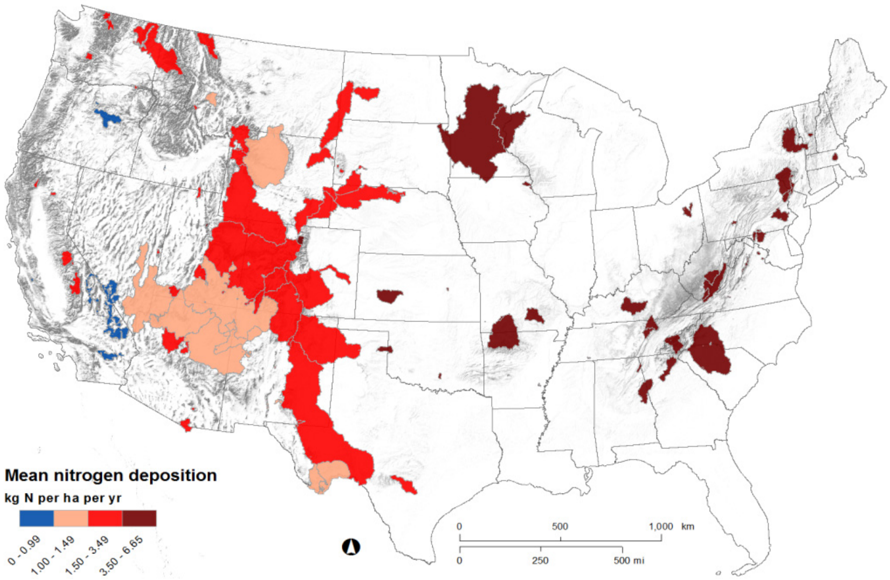


Fig. 4. N deposition in park upstream watersheds, with legend categories reflecting critical loads described by Baron *et al.*, (2011) for different areas of the US.

Rural development (<7 housing units km^{-2}; Theobald, 2005) has already occurred over extensive areas in most park upstream watersheds, and there is great concern about the rate of development of rural landscapes around parks (Hansen *et al.*, 2005; Wade & Theobald, 2009; Radeloff *et al.*, 2010). Increases in the extent of low-density housing in previously undeveloped areas has numerous biological impacts (Hansen *et al.*, 2002, 2005) and housing development is increasingly recognized as a primary driver of ecological processes and as a threat to biodiversity (McKinney, 2002; Miller & Hobbs, 2002). In the Greater Yellowstone Ecosystem, which is threatened by exurban development, riparian habitat, elk winter range, migration corridors, and other important habitat and biodiversity indices are expected to experience substantial conversion (between 5% and 40%) by 2020 (Gude *et al.*, 2007). Hence, this driver will be increasingly important for ongoing and future management of park watersheds.

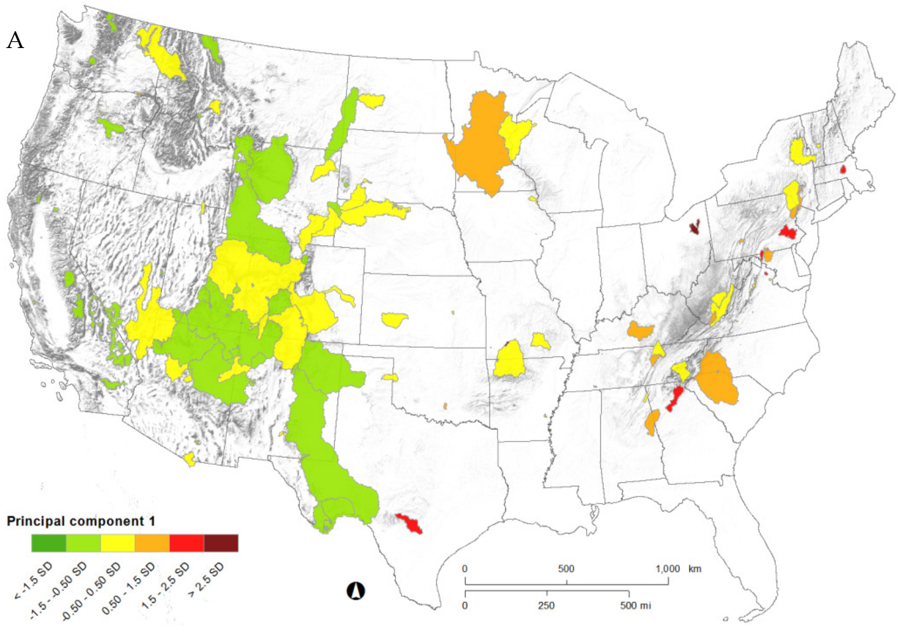
Lastly, dam density is characteristically low in most park upstream watersheds (Fig. 3; mean = 0.02 dams/km^2), but it is important to note that ecologically relevant thresholds for this variable are also low and likely close to this mean for many natural resources, especially when considered in the context of dam size. For example, a single large dam may affect water temperatures and benthic communities for hundreds of kilometres downstream (Baxter, 1977). In addition, higher densities of small dams may have cumulative effects on physicochemistry and macroinvertebrate diversity that exceed those of large dams (Mantel *et al.*, 2010). Single dams may also create serious obstacles to the long-range movement of fish, either upstream (e.g., anadromous salmon) or downstream (e.g., catadromous eels). In brief, dams have pervasive and varied effects on aquatic resources (Ward & Stanford, 1979), and the analyses presented here would greatly benefit from an expanded set of ecologically informative variables and thresholds related to impoundments.

3.2 Which landscape factors explain most variation in park upstream watersheds?

Using the human driver and conservation context variables shown in Figure 3, plus additional physical landscape variables described under landscape variables and data sources (Section 2.2), we conducted a PCA to understand which of the 21 landscape factors explained most of the among-park variation in upstream watershed context. Principal components 1 and 2 (PC1, PC2) explained 51% and 15% (respectively) of the variation (66% total). PC1 loaded positively on several variables related to urban development, while PC2 loaded positively on variables related to both agriculture and N deposition, and negatively on the amount of protected area (Table 3). According to both axes, higher values (denoting higher urban development, agriculture, and N deposition; less protected area) are associated with parks east of the Rocky Mountains (Fig. 5). Dam density loaded most strongly on PC4, but this axis explained only 6% of the variation and is thus not shown.

Variable	PC1	PC2
Urban development	0.29	-0.12
Low intensity development	0.29	-0.12
Population density	0.28	0.04
Suburban housing	0.28	-0.14
Urban housing	0.27	-0.12
Medium intensity development	0.27	-0.18
Developed open space	0.27	-0.01
High intensity development	0.26	-0.18
Agriculture	0.17	0.42
Cultivated crops	0.09	0.38
Rural housing	-0.04	0.38
Pasture/hay	0.18	0.31
Nitrogen deposition	0.16	0.30
Protected area	-0.14	-0.28
Commercial/industrial	0.25	-0.21
Housing density	0.24	0.16
Exurban housing	0.23	0.20
Impervious surface	0.22	-0.08
Weighted road density	0.17	-0.08
Owner density	0.06	-0.13
Dam density	0.13	-0.04

Table 3. Principal component analysis loadings by variable for axes 1 and 2 (PC1, PC2). Values are grouped on each column to facilitate interpretation of the axes.



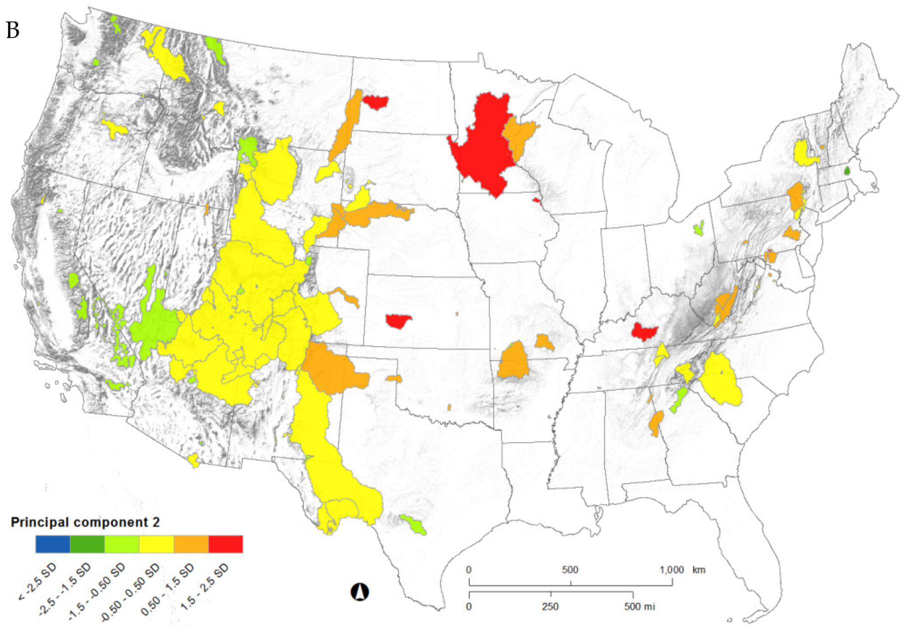


Fig. 5. Principal component scores 1 (A) and 2 (B) shown for park upstream watersheds. Orange and red colours denote watersheds that have higher PC scores (higher threat), in units of standard deviations (SD).

3.3 What can we infer about the condition of park freshwater resources?

Based on the percentage of impaired waterway, 62%, 64%, and 70% of parks (respectively) have less than 5%, 10%, and 20% of their total waterways in non-compliance with federal Clean Water Act sections 303(d) and 305(b) (Fig. 6). However, in this context it is important to note that 'impairment' standards vary by state and are generally less stringent than critical ecological thresholds in most parks. Furthermore, the sources of waterway 'impairment' do not all originate from park upstream watersheds. For these reasons, one would not *a priori* expect a substantial amount of among-park variation in waterway impairment to be explained solely by the landscape dynamics of upstream watersheds. We find that the percentage of park waterway impaired is positively correlated with PC1, and that this variable explains approximately 26% of variation.

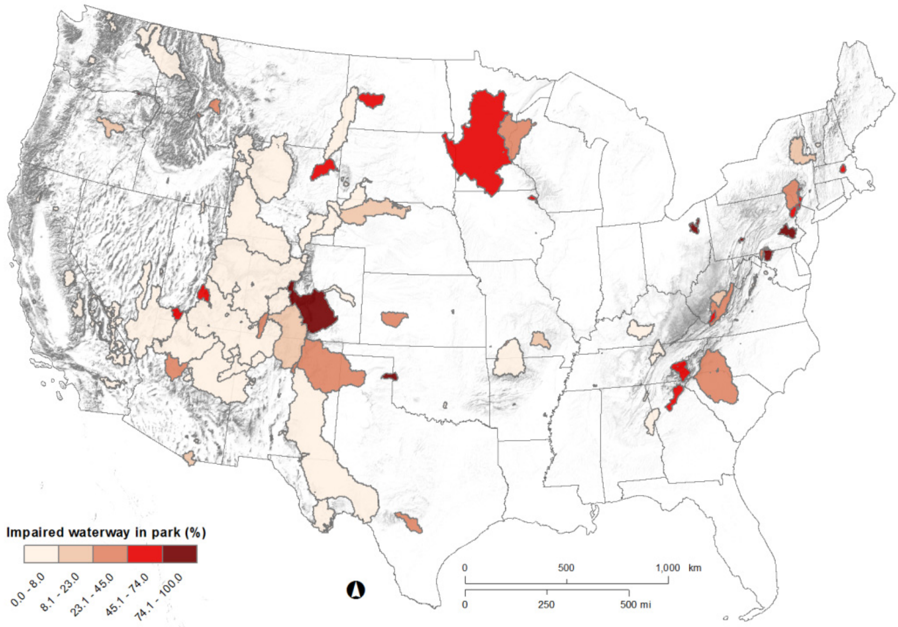


Fig. 6. The percentage of impaired waterway in focal parks. Note that the summary statistic was calculated for each park, but results are symbolized here by park upstream watershed to facilitate comparisons with the other maps.

When compared to ecological threshold values for poor or good water quality (e.g., Van Sickle *et al.*, 2006; Wazniak *et al.*, 2007; Riva-Murray *et al.*, 2010), water quality in and near most parks is in a good range. These results reflect the landscape location of most park watersheds, which tend to include a high portion of natural land cover and a relatively small area of cropland or intensive development. Using simple regression analyses, we generally found weak relationships between STORET water chemistry variables and watershed landscape variables. Certain attributes of the data likely contributed to our inability to link these factors. We wished to evaluate the ability of large, broad-extent databases to inform regional and national-scale analyses, and we thus began our analyses with approximately 2 million observations. The large number of observations required automated processes to screen data. For these preliminary analyses, we did not attempt to correct for factors such as season, variation in sampling effort, or flow regime. Despite the absence of strong statistical associations between water chemistry and landscape context, regional patterns were apparent for most of the chemistry variables we examined, such as phosphate-phosphorus (Fig. 7).

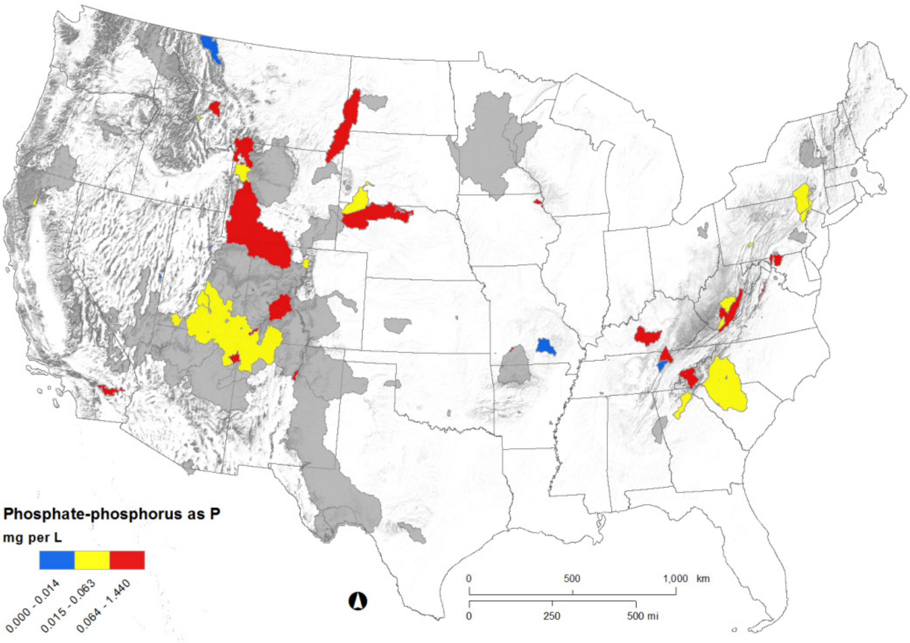


Fig. 7. Concentration of phosphate-phosphorus in focal parks, with legend categories reflecting conservative critical thresholds described by Van Sickle *et al*., (2006) for total P. Note that concentrations were calculated for each park with 3 km buffer, but results are symbolized here by park upstream watershed in order to facilitate comparisons with the other maps. Watersheds in light grey denote parks that were not sampled for this metric.

The absence of strong statistical relationships between landscape and water quality variables in our national-scale assessment indicates the need for more sophisticated analyses when working at these very broad scales and with generalized databases. Other studies have found considerably stronger relationships between land cover and water chemistry (e.g., King *et al*., 2005; Wickham *et al*., 2005; Riva-Murray *et al*., 2010). Our future efforts will include more sophisticated processes for screening water chemistry data, and additional analyses. For example, King *et al*., (2005) evaluated a water quality index based on binary (0, 1) values for predictor variables that were above or below a quality threshold. Their index was the sum or four predictor variables. The binary transformation effectively addresses issues with high variance in the predictor variables, and it simplifies estimation and interpretation of the index. In addition, evaluations of the relative contributions of land cover versus broad-scale environmental setting to determining water chemistry are ambiguous and clearly scale-dependent (e.g., compare King *et al.*, 2005; Wickham *et al.*, 2005; Goldstein *et al.*, 2007). Our analyses combined all samples for a given park so we could reach conclusions at the scale of an aggregated park upstream watershed. In some cases, this procedure merged samples from contributing watersheds that differed dramatically in land use patterns and threats to small-scale watersheds (e.g., Delaware Water Gap; Gross *et al.*, 2011). Future analyses of land use effects on park water resources will likely need to resolve data at a finer spatial scale, perhaps in the form of hierarchical models. An appropriate management-relevant improvement would be to conduct local and regional-scale analyses on watersheds upstream of sampling sites, and then extrapolate these results to park watersheds within relevant ecological regions (Rohm *et al.*, 2002).

3.4 What are the major challenges and opportunities for managing park upstream watersheds?

Among the 151 focal parks, the big challenges identified by these analyses for managing park upstream watersheds relate to three major categories: urban development (PC1, Fig. 5A), agriculture and diffuse rural development (PC2, Fig. 5B), and N deposition (Fig. 4). Habitat fragmentation and alteration due to dams is undoubtedly a fourth major challenge, but one that we were unable to adequately quantify in this analysis. Nonetheless, the assessment of landscape context revealed that practically all parks are threatened in their respective geographies by N deposition, and parks east of the Rocky Mountains are especially threatened by development and agriculture. Importantly, this is not to say that parks in the western US are unthreatened by historical changes in land cover and land use. When compared to eastern parks the upstream watersheds of western parks are not presently as impacted by these factors, but critical ecological thresholds may still be exceeded in certain areas (e.g., Porter *et al.*, 2005; Porter & Johnson, 2007). Furthermore, human population and housing projections suggest that many western parks will be increasingly challenged by development pressures in the coming decades (Theobald, 2005; Radeloff *et al.*, 2010).

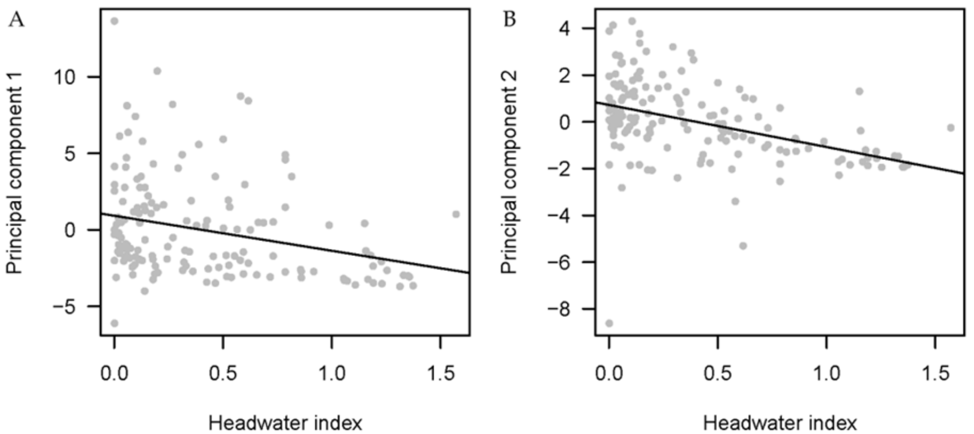


Fig. 8. Principal component scores 1 (A) and 2 (B), versus the headwater index (arcsine transformed), for 151 focal park upstream watersheds.

In the face of these monumental challenges, opportunities for managing park upstream watersheds are generally positively related to the headwater index – the proportion of the upstream watershed that exists within park boundaries. Managers of headwater parks obviously have the greatest direct management control over upstream watershed issues. Examples in this category include large National Parks in the western US: Yellowstone, Rocky Mountain, Sequoia and Kings Canyon, Yosemite, and Mount Rainier. In addition, owing to the strong human land cover and land use variables loading into PC1 and PC2, the two axes are negatively related to the headwater index (Fig. 8). From these relationships we can identify particular parks that – based on their headwater index – have characteristically low values for PC1 or PC2. In effect, these are parks with upstream watersheds that are relatively unchallenged by human drivers of landscape change, at least considering that significant portions of their upstream watersheds lie beyond park boundaries. Management opportunities for these parks lie in working collaboratively with other land owners to maintain protection of the upstream watershed. Example parks in this regard include Guilford Courthouse National Military Park (PC1), Chattahoochee River National Recreation Area (PC1), Effigy Mounds National Monument (PC2), and Arkansas Post National Memorial (PC2).

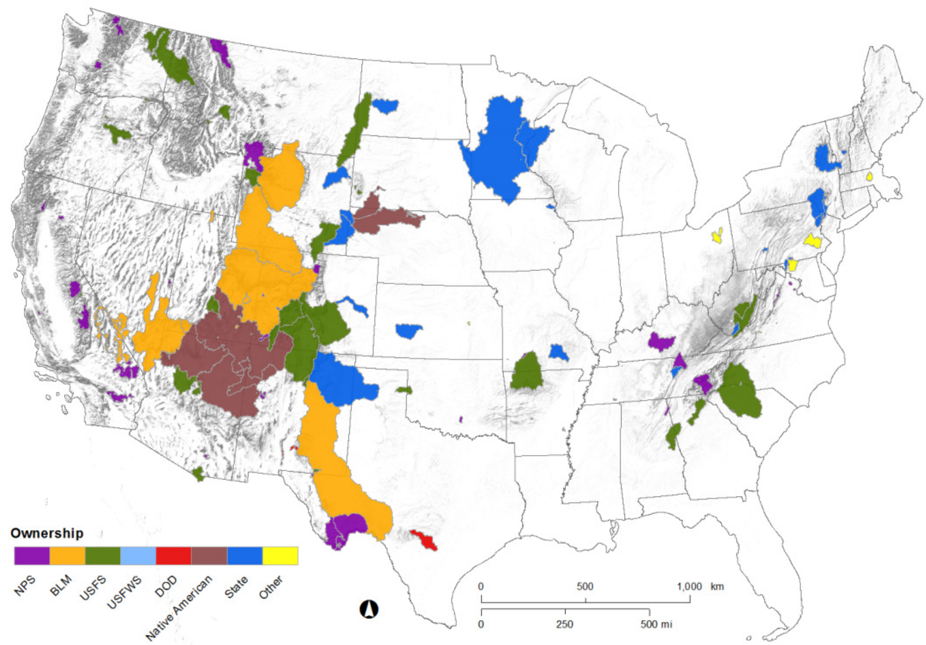


Fig. 9. Dominant owners of conservation land in focal park upstream watersheds. NPS = National Park Service, BLM = Bureau of Land Management, USFS = US Forest Service, USFWS = US Fish & Wildlife Service, DOD = Department of Defense.

Conservation partnerships are challenging to promote, in part due to varied and sometimes conflicting missions of the partners, and perhaps also due to an insular history of managing for resources within ownership boundaries. Nevertheless, partnership opportunities may initially be evaluated using a simple landscape metric like the density of landowners that manage lands for conservation. Although this variable did not emerge as a major factor explaining among-park variation in watershed context (Table 3), it can be very useful for particular parks seeking to understand the potential diversity of partners that need to be engaged, as well as the dominant landowners that control most areas upstream (Fig. 9). The recognition that neighbouring landowners share a common responsibility for managing resources in the face of landscape-level anthropogenic change has motivated actions at local to national scales to form new partnerships. It has also recently stimulated the establishment of the Department of Interior (DOI) Landscape Conservation Cooperatives (LCCs) and regional Climate Science Centers (DOI Secretarial Order 3289).

Private lands not held for conservation pose a separate and distinct set of challenges and opportunities for managing park upstream watersheds. Although not shown in Figure 9, non-conservation private lands encompass approximately 61% of the US, and they thus dominate many park upstream watersheds (Fig. 10). While it is challenging to coordinate a large number of different private landowners, such coordination may be facilitated when private lands share a common land use. For example, private landowners in an area dominated by cultivated crops may share problems with ditch erosion (i.e., increased time and costs with ditch maintenance), which also poses sedimentation challenges to water resources in a downstream park. Despite different concerns over the threat, there would be a united interest in identifying creative solutions to the problem. Non-governmental organizations (NGOs) have traditionally played an especially important role in coordinating private-public partnerships. Such partnerships may also be promoted through newly established LCCs.

3.5 Next steps

There are several important ways to build upon the analyses presented here. To evaluate a wider range of anthropogenic landscape stressors and pollutants, it is important to consider other areas of analysis besides upstream watersheds. Other ecologically informative areas of analysis could include downstream watersheds, ecoregions, or a local area that is proximate to the management unit (e.g., 30 km buffer or a protected area centered ecosystem, PACE; Hansen *et al.*, 2011). Using these varied areas of analysis would extend our framework to consider other water quality response variables that are affected by pollutants that traverse the landscape in different ways. In addition to new water resource response variables, it would also be useful to extend the analyses to consider point source drivers and their spatial proximity to parks based on flow length. However, given that these can vary so dramatically by geography, both in terms of point source type and magnitude, the explanatory power of these additional landscape predictors may prove most useful in analyses of parks at local to regional scales. Beyond the human drivers and conservation context of park upstream watersheds considered here, future analyses need to explicitly consider the ecological benefits and buffering potentials of natural systems. While some of these variables – like the percentage of natural land cover types – will be inversely correlated with many of the landscape stressors (e.g., percentage urban, percentage agriculture), others related to landscape pattern (Riitters *et al.*, 1995, 2007, 2009a, 2009b) and habitat connectivity (Hilty *et al.*, 2006; Theobald, 2006; Goetz *et al.*, 2009; Galpern *et al.*, 2011) will provide key management insights at local to regional scales.

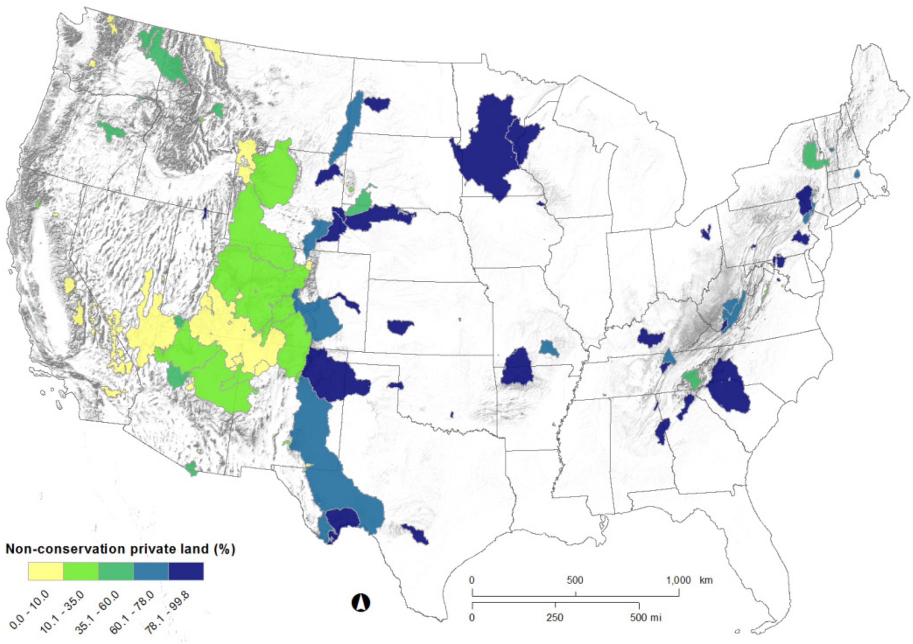


Fig. 10. Percentage of non-conservation private land in focal park upstream watersheds.

4. Conclusion

We demonstrate a GIS framework for quantifying broad-scale landscape dynamics of park upstream watersheds and interpreting those analyses in the context of park water resources and watershed management potential. The framework is valuable for assessing NPS-wide opportunities and challenges associated with preserving water resources across an entire network of management units. Because it is founded on publically available data and methods, which were chosen based on mechanistic relationships between landscape-scale factors known to affect protected areas (Hansen & DeFries, 2007) and water resources (Allan, 2004), the framework may be readily applied to other systems of protected areas in the US, and also to protected areas in other parts of the world with comparable landscape and water resource data. When applied to 151 focal parks in the contiguous US, we demonstrate how (1) major anthropogenic stressors upstream from parks vary geographically, both in terms of magnitudes and critical ecological thresholds (e.g., N deposition), (2) water chemistry and impairment observations from most parks are within a good range, reflecting the overall landscape context of parks, (3) certain non-headwater parks are surprisingly unchallenged by upstream stressors that affect water quality, and (4) parks vary dramatically in terms of the public and private partnership opportunities for coordinating watershed management. While these findings do not provide park-specific recommendations for managing water resources, they are foundational to helping us better understand park watersheds and water quality in a comparative NPS-wide context, which in turn may inform interpretations of site-level analyses at policy-relevant scales.

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3

Sustainable Management of Large Scale Irrigation Systems: A Decision Support Model for Gediz Basin, Turkey

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1. Introduction

While water on a global scale is plentiful, 97% of it is saline and 2.25% is trapped in glaciers and ice, leaving only 0.75% available in freshwater aquifers, rivers and lakes. About 70% of this fresh water is used for agricultural production, 22% for industrial purposes and 8% for domestic purposes. Increasing competition for water for domestic and industrial purposes is likely to reduce the water available for agriculture. Thus, water scarcity is being increasingly accepted as a major limitation on increased agricultural production and food security in the 21st century (Yazar, 2006). Climate change and hydric stress are limiting the availability of clean water. Overexploitation of natural resources has led to environmental unbalance. Present decisions relative to the management of hydric resources will deeply affect the economy and our future environment (Lermontov et al., 2011).

In developing countries, agriculture continues to be an important economic sector as it makes a significant contribution to national incomes and economic growth. As water scarcity intensifies in many regions of the world, better management of irrigation is becoming an issue of paramount importance (Hussain et al., 2007). Skilled management of irrigation should start from planning at the regional level (Lorite et al., 2007). The main problem in planning the management of deficit resources is how to allocate them among multiple users efficiently and equitably by considering the social, economic and political issues, while considering the heterogeneity in soils, crops and climate and the complexity of the water distribution system (Brumbelow et al., 2007; Chambers, 1988; Kilic & Ozgurel, 2005). Sustainable irrigation water management should simultaneously achieve two objectives: sustaining irrigated agriculture for food security and preserving the associated natural environment. A stable relationship should be maintained between these two objectives now and in the future, while potential conflicts between these objectives should be mitigated through appropriate irrigation practices. Cai et al. (2003) carried out an investigation on sustainability analysis for irrigation water management in the Aral Sea Region. This study presents an integrated modeling framework for sustainable irrigation management analysis and applies it to analyze irrigation water management. Based on the modeling outputs, alternative future of the irrigation practice in the region were explored and it was found that to maintain current irrigation practices would lead to worsening environmental and economic consequences. Investments in infrastructure improvements (about annualized US $ 299 million) and crop pattern change would be necessary to sustain the irrigated agriculture and the associated environment in the region. Evans et al. (2003) carried out an investigation on efficiency and equity in irrigation management. The objective of this study was to address the problems of inefficiency and inequity in water allocation in the El Angel watershed, located in Ecuador's Sierra region. Water is captured in a high-altitude region of the watershed and distributed downstream to producers in four elevation-defined zones via a system of canals. Upstream and downstream producers face different conditions with respect to climate and terrain. A mathematical programming model was created to study the consequences of addressing chronic water scarcity problems in the watershed by shifting water resources between the four zones. The objective function of the model maximizes producer welfare as measured by aggregate gross margin, subject to limited supplies of land, labor and water. Five water allocation scenarios ere evaluated with respect to efficiency in land and water use and equity in income distribution. Results revealed that although water was the primary constrained resource downstream, in the upstream zones, land was far more scarce. The current distribution of water rights did not consider these differences and therefore was neither efficient nor equitable. Improvements in efficiency and equity were associated with 1) a shift of water to the lower zone, and 2) the use of lower levels of irrigation intensity upstream. A linear optimization model was used in this investigation instead of real-time water allocation programming for different growing stages of crops.

Generally, optimal multi-cropping patterns and irrigation areas associated with appropriate reservoir operation and irrigation scheduling are essential for increasing the overall efficiency of reservoir-irrigation systems. Speelman et al. (2008) analyzed the efficiency with which water was used in small scale irrigation schemes in North-West Province in South Africa and studied its determinants. In the study area, small-scale irrigation schemes play an important role in rural development, but the increasing pressure on water resources and the approaching introduction of water charges raise the concern for more efficient water use. The Data Envelopment Analysis (DEA) techniques and sub-vector efficiencies were used in the study. This process was carried out under constant returns to scale (CRS) and variable returns to scale (VRS) conditions. The most important aspect of operation is distribution of the right quantity of water to the crops at the right time. An optimal multi-cropping pattern is important, since it provides better opportunities for water conservation and reduces the impact of water constraint on the system (Georgiou & Papamichail, 2008; Hsiao et al., 2007;). Bartoloni et al. (2007) carried out an investigation in order to evaluate the impacts of agriculture and water policy scenarios on the sustainability of selected irrigated farming systems in Italy. Five main scenarios were developed reflecting aspects of agricultural policy, markets and technologies: Agenda 2000, world market, global sustainability, provincial agriculture and local community. These were combined with two water price levels, representing stylized scenarios for water policy. The effects of the scenarios on irrigated systems were simulated using multi-attribute linear programming models representing the reactions of the farms to external variables defined by each scenario. In this study, five Italian irrigated farming systems were considered: cereal, rice, fruit, vegetables and citrus. The results showed the diversity of irrigated systems and the different effects that water pricing policy might produce depending on the agricultural policy, market and technological scenarios. On the other hand, effects of real-time irrigation programming at network level were not evaluated on water and agriculture policy scenarios in this investigation. Jalal et al. (2007) developed a model for optimal multi-crop irrigation areas associated with reservoir operation policies in an irrigation system. The objectives were to maximize the annual benefit of the system by supplying irrigation water for a proposed multi-crop pattern over the planning period. An irrigation program wasn't developed under real-time conditions at the system level.

In addition, it is complicated to analyze the management of deficit resources from the points of view of social, economics and politics, which constitute the various dimensions of management planning. Farmers decide on which crops to grow and on the associated use of resources such as land, labor, water and capital. Governments, on the other hand, develop policies (e.g., subsidies, taxation, and infrastructural developments) that are targeted at influencing decisions made at the farm level in order to achieve aggregated changes which are deemed desirable on a municipal, provincial or national scale. At national level, overall policies and decisions are formulated on sectoral allocations of resources and economic activities. Strategies, policies and programs for sectoral development are included in sector plans. At sub-national level, potentials, constraints and objectives for agricultural development are identified. In this multi-level planning approach, the plans at different levels have to be consistent and interlinked (Acs et al., 2007; Laborte et al., 2007; Mousavi & Ramamurthy, 2000;). Clemmens (2006) carried out research on improving irrigated agriculture performance through the water delivery process. Reasons for poor performance of the schemes were discussed and a method was proposed to improve its performance. According to this research, the main problem was that operation of the irrigation systems was not tied to productivity. As a result, the dispersive nature of the large open canal distribution systems causes extreme variability in water delivery service to users. Diaz et al. (2007) developed a model using data from an on-demand pressurized water distribution network located in Sector VIII of the Genil-Cabra irrigation district of Santaella, Cordoba, Spain to simulate an irrigation season, and calculate the flows that circulate in the system at any given time during the irrigation day. Water demand frequencies were estimated by using the results from model solution. Statistical distribution approach was used in this process. In addition, the most appropriate periods were studied for determining peak demand. The results showed that the statistical methods slightly underestimated demand. It was concluded that a better fit is achieved when a more flexible distribution such as Gamma Distribution is used.

Haie & Keller (2008) proposed two efficiency models: one is based on water quantity, and the other on quantity and quality, with the possibility of considering water reuse in both. These models were developed for two scales: the first was called Project Effective Efficiency, and the second Basin Effective Efficiency. The latter gives the influence of project on water resources systems of the basin while the former does not make such connection to the whole basin. The concept of equity in water allocation between large numbers of users in temporal and spatial dimensions weren't taken into consideration under the real-time programming conditions. Du et al. (2009) evaluated the Soil and Water Assessment Tool (SWAT) model for estimation of continuous daily flow based on limited flow measurements in the Upper Oyster Creek (UOC) watershed. Among the five main stem stations, four stations were statistically shown to have good agreement between predicted and measured flows. SWAT underestimated the flow of the fifth main stem station possibly because of the existence of complex flood control measures near to the station. SWAT estimated the daily flow at one tributary station well, but with relatively large errors for the other two tributaries. Any water allocation plan wasn't prepared for the district. Varis & Abu-Zaid (2009) carried out an investigation on socio-economic and environmental aspects of water management in the 21st century: trends, challenges and prospects for the Middle East and North Africa (MENA) region. Garizabal et al. (2009) carried out an investigation in order to analyze the evolution of the agro-environmental impact in a traditional irrigation land of the middle Ebro Valley (Spain) which was experienced changes in its management. It was determined that the drought of 2005 caused more intensive water use (86%), increasing in 33% the irrigation efficiency when compared to 2001 (53%), even though a high hydric deficit (24%) was caused. Ryu et al. (2009) developed a decision support system for sustainable water resources management in a water conflict resolution framework to identify and evaluate a range of alternatives for the Geum River Basin in Korea. Working with stakeholders in a "shared vision modeling" framework, management strategies were created to illustrate system tradeoffs as well as long term system planning. A multi-criterion decision making approach using subjective scales is utilized to evaluate the water resource allocation and management tradeoffs between stakeholders and system objectives. The real-time programming wasn't carried out in this process, and changing efficiency values for the systems in temporal and spatial dimensions weren't taken into consideration. Sheild et al. (2009) carried out an investigation to identify and quantify stakeholder references pertaining to water management programs in order to improve water policy design. The relative importance of water management attributes was evaluated and willingness-to-pay values were estimated. Results showed that the majority of respondents weighed preserving stream health and Hawaiian cultural practices in water allocation decisions and were willing to pay $4.53 per month per household to improve stream health to an excellent condition. These results highlight the need to strongly align watershed-level preferences to better balance in-stream and offstream demands to help guide water managers to make more effective water allocation decisions.

In this investigation, the real-time irrigation programming model MONES 4.1 developed by Kilic (2010) was applied to the irrigation system known as Sector VII which is served by 28 tertiary canals in the Right Bank Irrigation System of Ahmetli Regulator in the Lower Gediz Basin, Turkey. Irrigation programs from the model for different periods were analyzed, and the results were compared with the actual irrigation applications in the system.

2. Description of the study area

This investigation was carried out on the commands of 28 tertiary canals in Irrigation District of Sector VII in Ahmetli Right Bank Irrigation Network in Lower Gediz Basin Irrigation System in Turkey. The Basin is located within the Aegean Region of western Turkey at latitude 38^0 04' - 39^0 13' N, and longitude 26^0 42' - 29^0 45' E. The main water source for the Lower Gediz Irrigation System is the Gediz River, which is 275 km in length. Drainage area of the basin is roughly 17219 km^2 (Figure 1). The Gediz Basin is a river deposit basin formed with the alluvium transported by the Gediz River and its tributaries. The basin's topography is characterized by hills and rolling country. The tributaries of the Gediz River have been filled with eroded silt and sediment by erosion. For this reason, flood flows can easily overtop the river banks. These conditions create a problem of high groundwater in the basin, especially near the sea where the slope is minimal (Girgin et al., 1999; Kilic, 2004; Topraksu, 1971, 1974; Yonter, 2010).

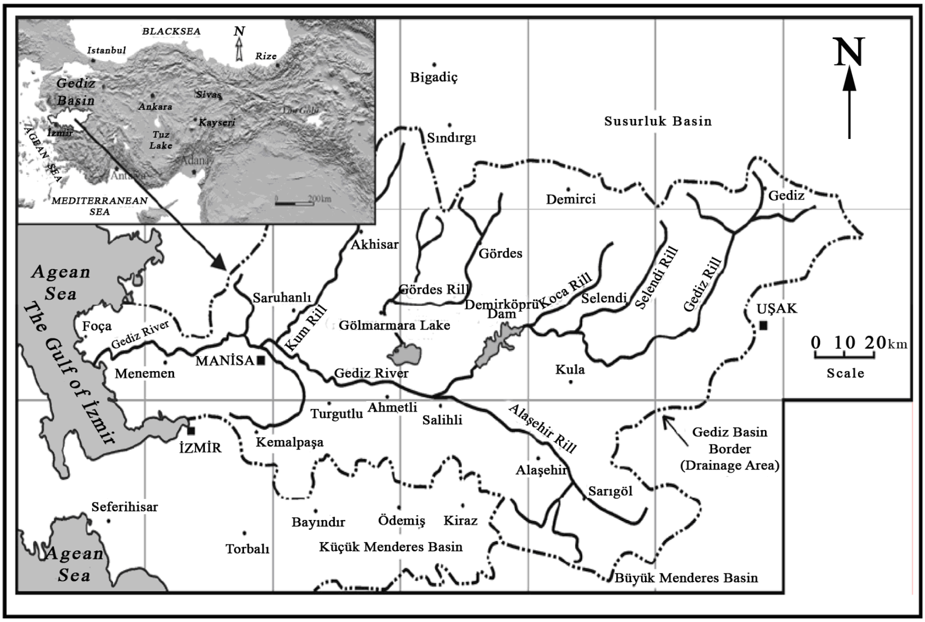

Fig. 1. General plan of the Gediz Basin in Turkey.

The Demirköprü Dam was constructed on the Gediz River in 1960 for irrigation, energy and flood control. Total water storage in the dam reservoir determines the volume and duration of irrigation water supplies to Gediz Basin System. Roughly 751 million cubic meters of water per year is released to the Lower Gediz Irrigation System by means of three regulators constructed on the river: from upstream to downstream, Adala, Ahmetli and Emiralem (Kilic & Tuylu, 2010).

For the past decade, there has been a scarcity of water in the Lower Gediz Basin because of the increase in urban and industrial demands (Svendsen et al., 2001). Unplanned production patterns, inadequate system capacity, poor distribution and management of water, large numbers of divided and small sized plots for cropping, and uncontrolled and inappropriate use of water by the farmers are the major factors giving rise to low efficiency in the Gediz Basin Irrigation System. Water level or flow can be controlled from three points in the system: I- main regulator at the head of the main canal; II- offtake regulators at the heads of the secondary canals; and III- constant-head orifices at the turnout to each tertiary canal. The main and secondary canals are under upstream control.

The National Water Works (DSI) operates the major water control infrastructures, such as river regulators and dams. Also, water allocation to main canals is fixed by the DSI according to the size of command and cropping pattern. Irrigation associations are responsible for water delivery from the main canal to secondary canals. Water delivery to tertiary canals and plots is arranged by Village Irrigation Groups (VIGs) which are responsible to the irrigation association. VIGs are the lowest unit of the irrigation associations, and are responsible for collecting and submitting farmers' water demand forms and managing water distribution at tertiary canal level. Farmers report their water requirements to the VIGs one or two days before the desired irrigation date, and VIGs decide the allocation of water to the plots according to the reports from the farmers. During a fixed length of system rotation period, farmers receive water from the canals to their plots according to this plan. Especially in peak irrigation period and under water scarcity conditions, farmers in the tail end of the network cannot use the system equally and cannot receive an adequate amount of water on schedule. Because, the farmers especially in the head of the canals continue receiving water from the system and decide for themselves whether an adequate amount of water has been received. Disagreements between the farmers are handled by the VIGs or irrigation associations.

Tertiary name	Cotton (ha)	Grapes (ha)	Maize (ha)	Watermelons (ha)	Tomatoes (ha)
P.3	0.45	0.00	2.36	0.00	0.50
P.4	7.99	0.00	6.36	0.00	6.86
P.5	5.29	0.95	26.03	0.45	7.43
P.6	1.50	0.80	0.39	0.00	0.30
P.7	5.87	6.20	19.39	0.00	2.55
P.8	2.88	2.92	0.45	0.00	0.57
P.9	12.37	0.00	10.42	1.10	0.25
P.10	1.48	0.00	10.95	0.00	0.00
P.11	4.36	0.96	12.34	0.00	0.86
P.12	6.13	0.00	2.57	0.00	0.00
P.13	8.09	4.02	3.08	0.20	1.10
P.14	13.12	0.46	18.54	0.08	0.00
P.15	8.57	1.41	2.98	0.00	0.00
P.16	15.23	0.00	24.30	0.00	0.00
P.17	4.00	0.00	0.00	1.00	0.00
P.18	15.00	0.00	32.99	0.00	0.00
P.19	11.20	0.00	43.70	2.10	0.10
P.20	41.05	7.13	15.86	5.00	0.30
P.21	12.54	4.00	3.42	0.00	0.00
P.22	11.14	10.76	10.90	0.00	0.00
P.23	19.42	4.64	4.43	1.00	0.00
P.24	9.97	1.25	16.15	1.49	0.00
P.25	2.57	4.14	0.00	0.00	0.00
P.26	19.02	4.37	26.59	0.00	0.00
P.27	0.00	2.81	0.00	0.00	0.00
P.28	0.61	0.00	0.00	0.00	0.00
P.29	0.00	1.02	0.00	0.00	0.00
P.30	1.02	5.31	5.53	0.95	1.21

Table 1. Crop pattern and size of the area irrigated by the canals.

In the research area, water charges are collected annually by the Gediz Irrigation Association according to the crop type and size of the area. In other words, water from the open canal irrigation system is priced in TL/ha, and is paid for as a single payment for the whole season. Thus, the number of irrigations and the amount of water used in irrigation applications is not important in pricing the water.

Apart from this, producers form crop patterns according to tradition and their own preferences. This has an adverse effect on the efficient management of these systems. In addition, there is a loss of productivity because of the great age of systems like the one under study here. Size of the area irrigated by the canals and the crop patterns are shown in Table 1. In the research area, cotton, maize, tomatoes, watermelons and grapes are grown in ratios of 37.69%, 46.89%, 3.45%, 2.09% and 9.88% (Gediz Irrigation Association Reports, 2007).

The district has a continental climate. Rain falls mostly in the winter months, while summers are dry. The effect of Aegean Sea is felt inland because the mountains run perpendicular to the sea. The land is irrigated in the period from May to September when rainfall is insufficient. Annual average temperature and rainfall (1975-2006) in the district are 16.9 ^{o}C and 704.6 mm respectively (DMI Reports, 2008).

3. Description of the irrigation programming model

3.1 Water allocation stages at network level

The program performs the real-time allocation of water at network level in three main stages: 1) allocation of water from the main canal to the secondaries, 2) allocation from secondary to tertiary canals, and 3) allocation to plots.

The entire network is divided into different segments in the program. This means that the main canal cross-section between the points where two consecutive secondaries receive water is the primary level segment; a secondary canal cross-section between the points where two consecutive tertiaries receive the water is the secondary level segment, and a tertiary canal cross-section between the points where two consecutive plots receive water constitutes the third level segment. Each different level of segment takes an increasing consecutive index value from head of the network to the end. Therefore, the spatial description of each segment is carried out in the system, and the operation of the program is performed interactively in order for each level of segment.

Four main components are described for each segment in the program: 1) inflow discharge to head of the segment, 2) water conveyance loss through the segment, 3) amount of water received for irrigation from the segment, and 4) outflow discharge from the end of the segment. These data constitute one of the main components of real-time water allocation program.

Water distribution stages in the program are performed by running the seven modules interactively in order. Water is received by the plots from the tertiaries. For this reason, the planning process for tertiaries is described in detail, so as to show the effects of water allocation programs at the level of secondaries and the plots. The planning processes for other levels are also carried out in similar ways.

3.2 Description of the main modules in the program

In this section, the modules for preparing real-time irrigation programs for tertiary levels will be described. One of the modules is the structural module. This component contains all the structural and hydraulic features of the network. The main parameters in this module are water carrying capacity and length of each secondary segment; the inflow discharge to head of the secondary cross-section; water conveyance efficiency and maximum water carrying capacity and size of the command of each tertiary. In this stage, it must be taken into consideration that water is delivered from secondary canals to the tertiaries, and these two allocation levels are described interactively in this module. Some parameters in the program are shown schematically together with the layout of the canals in Figure 2.

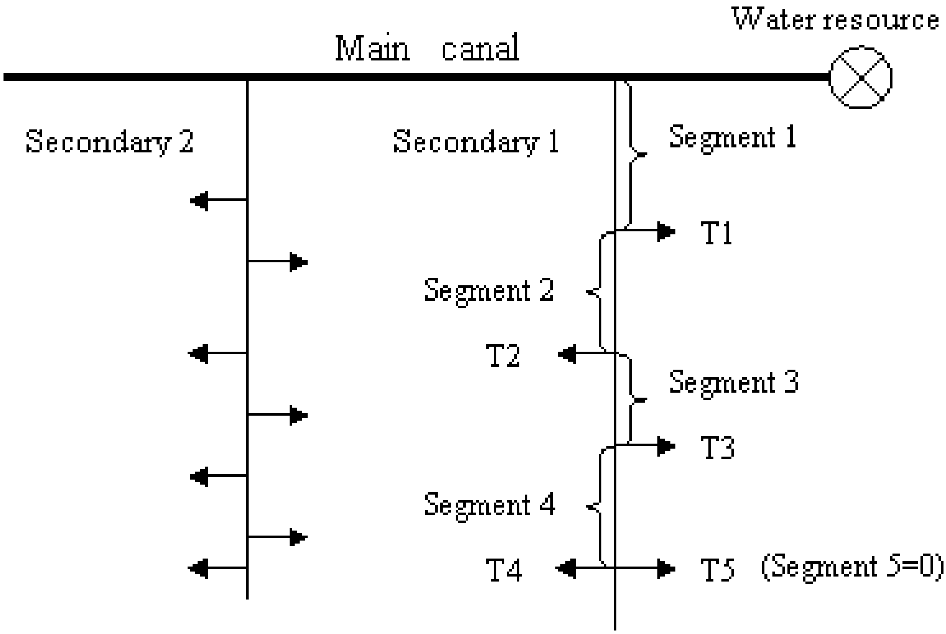

Fig. 2. Schematic description of parameters of the real-time programming model of an open canal system.

As seen on Figure 2, tertiaries T1-T5 receive water from secondary 1. The lengths of the secondary segments between these tertiaries are shown as Segment 1, Segment 2,.... Segment 5. Average flow velocities in the vertical cross-section of the canals, which are necessary in the description of hydraulic features of the system, were determined by the Velocity-Cross Section method as explained by Mays (1996). Water conveyance losses occurring in the canals were determined by Kilic & Tuylu (2010) according to the Inflow-Outflow method (ANCID, 2003). One of the interface forms containing the parameters explained above is shown in Figure 3.

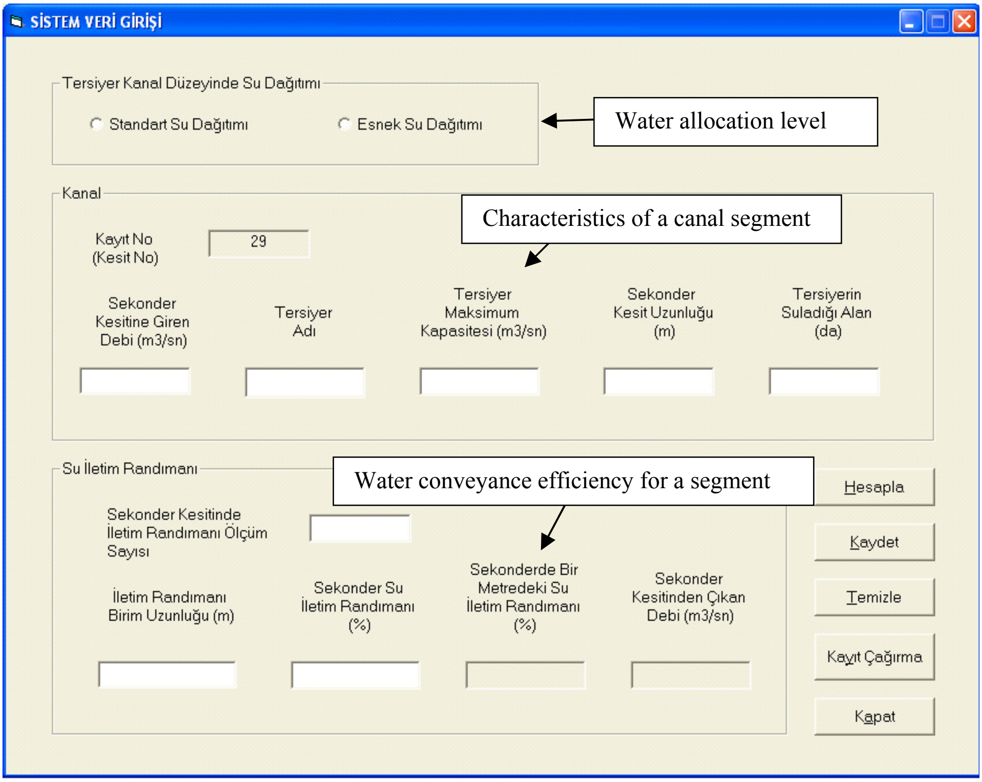

Fig. 3. The interface form containing some of the parameters of the model.

The second main module determines the canal rotation groups at system level. This process is based on determining the canal groups which cannot receive water at the same time. In order to obtain the highest benefit from the system, the planning process was carried out in accordance with the operation of canals at maximum capacity. In other words, it was ensured that canals received water from the network at maximum capacity. This application also constitutes one of the main principles of water allocation by the rotation method. This process was carried out by use of the formulas given below (Kilic & Anac, 2010).

$$QS_{mur} * (ESC_{mu} / 100)^{f} \geq QT\max_{mu(r+1)} \tag{1}$$

$$f = l_{m(r+1)} - l_{mr}$$

$$(l_{m(r+1)} - l_{mr}) \geq 0 \tag{2}$$

where, m = indices of secondary canals from head to the end of the network; u = indices of segments in secondary m from head to the end; r = indices of tertiary canals from head of the secondary to the end; QS_{mur} = discharge remaining in the secondary after water is received by tertiary r from segment u of secondary m (m^3 sec^{-1}); ESC_{mu} = water conveyance efficiency for segment u of secondary m (% $1km^{-1}$); $QTmax_{mu(r+1)}$ = maximum carrying capacity of the consecutive tertiary (r+1), receiving water from segment u of secondary m (m^3 sec^{-1}); l_{mr} = the distance from the point where tertiary r receives water to the head of secondary m (km); $l_{m(r+1)}$ = distance from the point where consecutive tertiary (r+1) receives water to the head of secondary m (km); f = Length of a secondary canal segment between the consecutive tertiaries r and (r+1) receiving water from secondary m (km).

Each tertiary canal validating the conditions indicated in formulas (1) and (2) will be in the same rotation group and can receive water in maximum capacity from the secondary at the same time. On the other hand, if the conditions are not validated by the tertiary, this canal will be in the consecutive rotation zone together with the tertiaries validating the conditions. The canal rotation groups were formed by carrying out the process repetitively for the entire network. Thus, the system is divided into different allocation zones to ensure efficient usage of resources and operation of the network.

The third module determines borders, sizes and numbers of the allocation zones devised by the model in the system. Total sizes of the commands irrigated by the canal rotation groups serving each allocation zone also describe the borders and sizes of these zones. Indices are given to the allocation zones in an increasing order from head of the network to the end. In the program, borders of the allocation zones are represented by the names and indices of the head and end segments of the canals irrigating the area. These borders are described by the formulas given below in the model.

$$AR = \sum_{z=1}^{nz_a} AT_{az} \quad \text{For } a = 1,\ na \tag{3}$$

where, a = indices of allocation zones in the system (in order from head of the network to the end); na = total number of allocation zones in the system; z = indices of tertiary canals delivering water simultaneously to allocation zone a (in order from head to the end of the secondary); nz_a = total number of tertiary canals delivering the water simultaneously to allocation zone a; AT_{az} = size of the area irrigated by tertiary z in allocation zone a (ha); AR = total size of the irrigated area in allocation zone a (ha).

In the fourth module, the lengths of irrigation times to be allocated to the zones during the system rotation period are determined in accordance with the principle of delivering equal amounts of water per unit of area in each allocation zone. In other words, whatever the location of a plot in the network, the capacity of the canal receiving water from the system, or the water conveyance efficiency, this plot will benefit from the water resource and system equally in temporal and spatial dimensions. This process is described for each canal rotation group which cannot receive water at the same time. The lengths of water allocation periods for different allocation zones in a given irrigation period were determined in four main stages as explained below.

In the first stage, ratio coefficient values were determined for each allocation zone in a definite rotation period. These calculations are formulated below.

$$Q\max_{ia} = \sum_{k=1}^{nk_{ia}} QT\max_{kia} \tag{4}$$

$$t_{ia} = A_a / Q\max_{ia} \quad \text{For a} = 1,\ \text{na} \ ;\ \text{For i} = 1,\ \text{ni} \tag{5}$$

where, a = indices of the allocation zones in the system (in order from the head of the network to the end); na = the total number of allocation zones in the system; i = indices of rotation periods (in order from the beginning of the irrigation season to the end); ni = total number of rotation periods during the entire irrigation season; k = indices of tertiary canals delivering water simultaneously to allocation zone a in rotation period i (in order from the head of the secondary to the end); nk_{ia} = the number of tertiary canals delivering water simultaneously to allocation zone a in rotation period i; $QTmax_{kia}$ = maximum water carrying capacity of tertiary k delivering water to allocation zone a in rotation period i (m^3 sec^{-1}); $Qmax_{ia}$ = sum of the maximum water carrying capacities of the tertiary canals delivering water simultaneously to allocation zone a in rotation period i (m^3 sec^{-1}); A_a = total size of the irrigated area in allocation zone a in rotation period i (ha); t_{ia} = ratio coefficient of allocation zone a for rotation period i.

In the second stage, the system factor was determined for a definite rotation period.

$$SF_i = R \Big/ \sum_{a=1}^{na} t_{ia} \quad \text{For i} = 1,\ \text{ni} \tag{6}$$

where, R = length of the rotation period for the system (hours); SF_i = system factor for the rotation period i.

In the third stage, length of irrigation time was determined for each allocation zone during a definite rotation period.

$$IRT_{ia} = t_{ia} * SF_i \quad \text{For a} = 1,\ \text{na} \ ;\ \text{For i} = 1,\ \text{ni} \tag{7}$$

where, IRT_{ia} = length of irrigation time for allocation zone a in rotation period i (hours).

In the fourth stage, the formula shown below was obtained when all the calculation processes in the previous stages were converted to a general equation.

$$IRT_{ia} = \left[A_a \Big/ \sum_{k=1}^{nk_{ia}} QT\max_{kia} \right] * \left[R \Big/ \sum_{a=1}^{na} t_{ia} \right] \quad \text{For a} = 1,\ \text{na} \ ;\text{For i} = 1,\ \text{ni} \tag{8}$$

As can be understood from the calculation process explained above, the planning is carried out in accordance with the operation of the system at maximum capacity. In addition however, plant pattern and soil features of the allocation zones may be different from each other, which means that the irrigation water requirements of the zones will be different from each other too. Determination of irrigation water requirements of allocation zones and analysis of water constraint levels occurring in tertiary commands is performed in the next module.

In the fifth module, irrigation water requirements of the crops grown in the command of each tertiary are determined as volume for a given period. The value of this parameter is used as a transition stage in determining the amount of water to be allocated from the resource to a given allocation zone. It is also used in determining the length of irrigation time necessary to meet the water requirements of the crops, and water deficits occurring in the canals in the entire network.

Irrigation water requirements and constraint levels occurring in the command of each tertiary canal were determined using the formulas given below.

$$WDV_{akci} = \Sigma(D_{akci} * A_{akc} * 10) \tag{9}$$

where WDV_{akci} = total amount of irrigation water requirement as volume of crop c grown in the command of tertiary k, in allocation zone a, for the rotation period i (m^3); D_{akci} = total amount of irrigation water requirement of crop c, irrigated by tertiary k, in allocation zone a, in rotation period i (mm). The value of this parameter was determined using a well known package, Cropwat (FAO, 1992). About 30-45% of available moisture between the permanent wilting point and field capacity was allowed to be depleted, and the soil moisture was refilled to field capacity at each irrigation. Exceeding the soil moisture depletion level by over 50% was not allowed, as explained by Doorenbos & Kassam (1979). A_{akc} = size of the growing area of crop c irrigated by tertiary k, in allocation zone a (ha).

Amount of irrigation water allocated to the crops grown in the command of a tertiary canal were determined by the formula given below.

$$AW_{kia} = QT\max_{kia} * IRT_{ia} * 3600 \tag{10}$$

where AW_{kia} = amount of irrigation water allocated to the crops grown in the command of tertiary k, in allocation zone a, during the rotation period i (m^3); $QTmax_{kia}$ = maximum water carrying capacity of tertiary k delivering water to allocation zone a in rotation period i (m^3 sec^{-1}); IRT_{ia} = length of irrigation time for allocation zone a in rotation period i (hours); 3600 = the coefficient converting hour to second.

Water constraint levels occurring in the command of each tertiary were determined by the formula given below.

$$WDL_{kia} = ((WDV_{akci} - AW_{kia}) / WDV_{akci}) * 100 \; (\text{if } WDV_{akci} \geq AW_{kia}) \tag{11}$$

where WDL_{kia} = water constraint level occurring in the command of tertiary k, in allocation zone a, in rotation period i (%).

In the fourth module, the length of irrigation time allocated for each zone during the system rotation period was determined in accordance with the operation of the network at maximum capacity. In the fifth stage on the other hand, the level is determined at which the irrigation water requirements of the crops can be met by the actual infrastructure of the system. For this purpose, water constraint levels occurring in each tertiary command are determined. One of the interface forms carrying out these processes in the model is shown in Figure 4.

Irrigation water requirements of the crops vary at different growing stages. There is not a linear relationship between the amount of water given to the system and yield of crops. Thus, the Yield Response Factor (ky) takes different values at each growing stage (Kilic, 2004). Numbers and borders of allocation zones, canal rotation groups, and length of irrigation times for the zones may change depending on the conditions in different periods. The MONES 4.1 (Kilic, 2010) package provides the real-time irrigation programs by taking into consideration of varying conditions in the system.

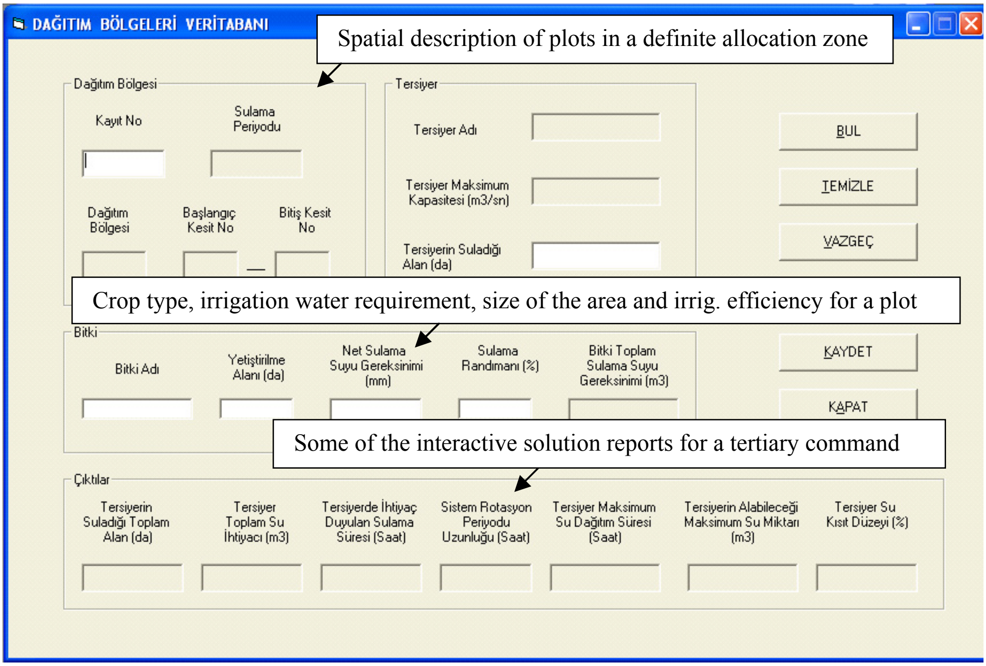

Fig. 4. A sample interface form used for description of the plant pattern, irrigation water requirements of the crops, and levels of water deficit in the system.

In the sixth module, alternative irrigation programs are prepared by changing the values of parameters in the program as desired. For example, water deficiency levels occurring in each tertiary canal can be determined by changing the length of system rotation period. Thus, the most suitable length of rotation period can be decided by taking into consideration the deficit levels occurring in the entire network. This module can derive alternative solutions for desired numbers of irrigation periods. Apart from this, adequate carrying capacity of the canals needed to meet the water requirements of the crops can be determined by running this module. Also, optimum size of command which can be irrigated by the infrastructure of the network in reality can be determined. In addition, the priority and degree of maintenance and renovation works of the system can be decided by this module. Thus, insight is provided to the decision maker into the use of limited labor and financial resources at an optimum level. In this process, the results of possible operation plans from the model solution can be analyzed before making a final decision on operation strategies of the system.

In the seventh module, detailed report files are prepared for each alternative solution, and these are presented to the decision maker as tables. Therefore, an evaluation can be achieved for the entire system. A sample report file interface form for this process is shown in Figure 5.

The flow chart of the MONES 4.1 model devising irrigation programs at network level is given in Figure 6.

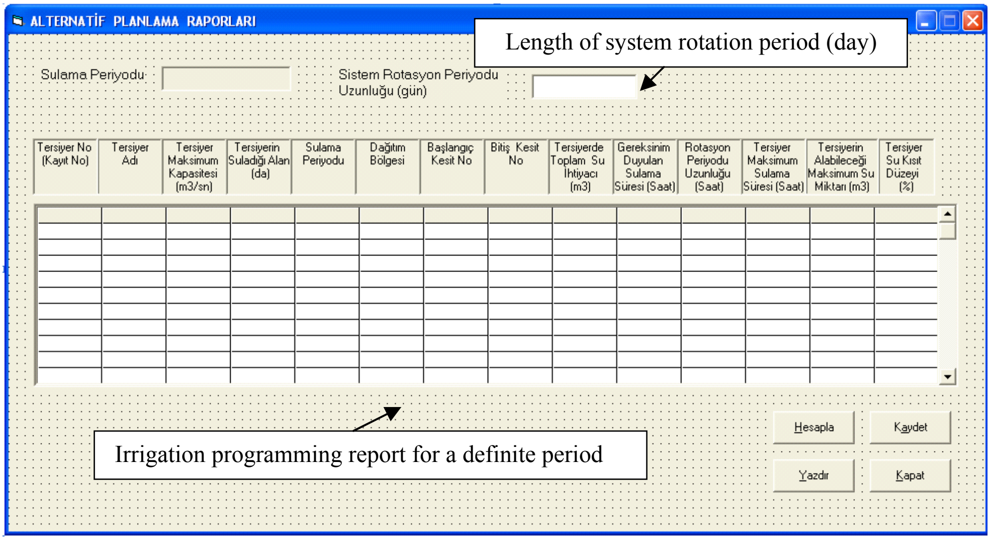

Fig. 5. A sample interface form for the preparation of alternative solution reports.

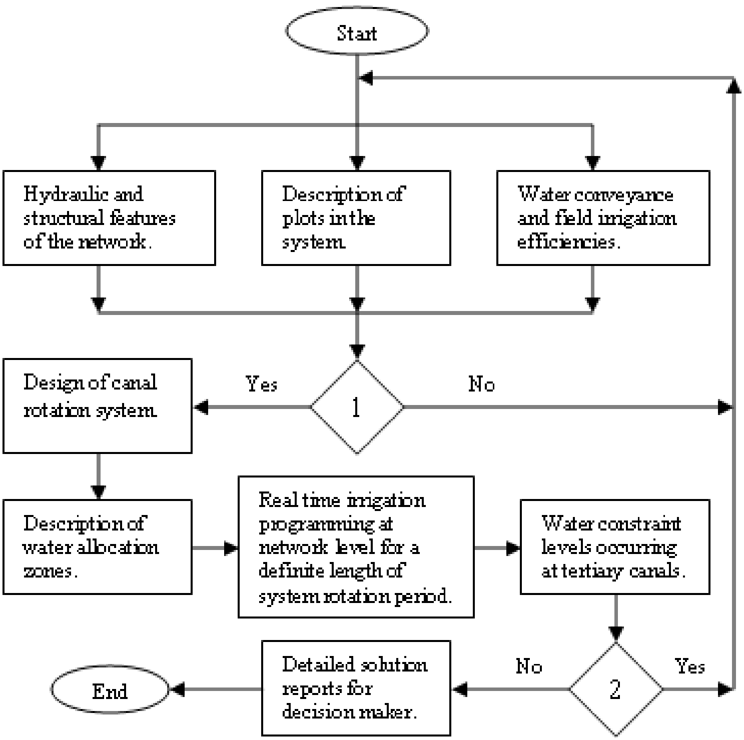

Fig. 6. Model flowchart for real-time irrigation programs.

Firstly, data input process to the related modules was carried out in the program (Figure 6). This step inquired whether data input to the system was completed or not. Another stage in running the model is derivation of alternative irrigation programs. If decision maker decides that alternative programs must be devised for a given irrigation period, the model is run again by the second conditional return, shown in the flow chart in Figure 6. By running this module, it is possible to derive alternative irrigation programs by making necessary changes to desired parameters in the model.

At the end of this process, optimum operation strategies for the system can be decided by analyzing the water constraint levels occurring in canals, the length of irrigation periods necessary for different allocation zones, the amount of water used in the network, and the allocation of deficit resources to different irrigation periods. Consequently, before deciding on an operation strategy for the system, the optimum program can be selected by analyzing alternative solutions of the model.

4. Results and discussion

Significant levels of differences occurred between the water allocation plan applied in the research area in reality and the model solution. It was determined that canal rotation groups, allocation zones and irrigation programs from the model solution were different from those applied in reality in the system.

In the research area, a 10 day system rotation period is applied by the current water allocation program in the network. Tertiaries are held open during this period by the Gediz Irrigation Association, and water is received in the plots by the farmers without any planning when it is released to the canals (Gediz Irrigation Association Reports, 2007). In other words, in the water allocation plan applied in reality, irrigation water is given to all the tertiary canals at the same time, and an attempt is made to irrigate the entire command in 10 days. This application prevents the operation of the system at maximum capacity and does not enable the optimum benefit to be obtained from production. Such a practice causes the irrigation water to be taken from the canals immediately, especially by the farmers whose plots are in the head of the network. Uncontrolled water allocation prevents it from being received in the desired amount and at the desired time by the farmers whose plots are in the tail end of the system. Consequently, it is not possible to provide social equity in temporal and spatial dimensions in use of the system and allocation of deficit resources to large numbers of users by means of the water allocation plan applied in the district in reality.

In addition, no scientific plant patterning has been carried out in the research area or elsewhere in Turkey. Thus, producers choose crop patterns according to tradition and market conditions. In this state, it is necessary to prepare real-time irrigation programs at network level, and the parameters necessary for optimum growing conditions must be taken into consideration. In this way, optimum crop yield and benefit can be obtained by using the system capacity at maximum level. Allocation Zones (AZ), canal rotation groups and size of irrigated areas obtained by running the irrigation programming model MONES 4.1 are given in Table 2.

Allocation Zone	Tertiary canal rotation groups	Total size of the irrigated area (ha)
AZI	P.3-P.22.	505.65
AZII	P.23-P.26.	115.04
AZIII	P.27-P.30.	18.46

Table 2. Allocation zones, canal rotation groups and total size of the commands in the MONES 4.1 model.

Three different allocation zones were determined in the research area, as maximum carrying capacity of the secondary canal is not adequate for delivering water to all tertiaries at the same time. The number of tertiary canals allocating water to AZ I, AZ II and AZ III also decreased progressively along the length of the secondary, as the capacity of the secondary canal diminishes from the head of the network to the end. In other words, fewer tertiary canals could deliver water at the same time to a given allocation zone at the end of the network than at the head, because of the progressive reduction of the secondary canal's capacity. For example, at the head of the network, 20 tertiary canals (P.3-P.22) can irrigate the command of AZ I at the same time, while only 4 tertiaries (P.27-P.30) can irrigate the command of AZ III simultaneously, as it is at the end of the network. In this way, all the canals in the network were operated in maximum level.

Maximum lengths of irrigation times (IRT) allocated for the zones (AZ) during the 7, 10, 11 and 12-day alternative system rotation periods (R) for the district are given in Table 3.

As can be understood from the Table 3, the maximum lengths of irrigation times allocated for different zones vary depending on the length of the alternative system rotation periods. These allocation times were planned in order to give equal amounts of water to the unit areas of different allocation zones.

Allocation Zones	Alternative system rotation periods			
	7 days (168 hours)	10 days (240 hours)	11 days (264 hours)	12 days (288 hours)
AZI	95.06	135.80	149.38	162.96
AZII	51.93	74.18	81.60	89.02
AZIII	21.01	30.02	33.02	36.02

Table 3. Lengths of irrigation times allocated for the zones during the alternative system rotation periods.

Irrigation water requirements of the allocation zones in different periods are different from each other. The whole irrigation water requirement of the allocation zones could not be met completely in the maximum length of irrigation time allocated for the zones during the system rotation period. This causes deficit irrigation applications. For this purpose, irrigation programs developed for each tertiary canal are analyzed in detail for each irrigation period. In this way it was possible to analyze the effects of the lengths of irrigation times on water deficits occurring in different periods.

In addition, irrigation times for the whole season are not determined as fixed time points at the beginning of the irrigation season in real-time programming. Irrigation times are determined in accordance with the irrigation water requirements of crops at different growing stages, size of area, location and soil features of plots receiving water from canals, infrastructure of the network, length and layout of canals, water carrying capacity of different canal segments, conveyance efficiencies and hydraulic features of the network. In this process, the most suitable length of system rotation period for the parameters stated above constitutes one of the main components in determining the irrigation times in real-time programming.

The MONES 4.1 package (Kilic, 2010) was run for the entire irrigation season in the research area, and irrigation programs were obtained. In order to bring out some of the main features of the model, three different irrigation periods were handled, beginning on 6th June, 10th July and 18th August, respectively. One of the main reasons for selecting these periods is to evaluate irrigation programs for different growing stages of the crops. Thus, the program was run for irrigation water requirements of the crops, which vary during the growing period, and the results were evaluated. The second main reason for selecting these periods was to investigate the irrigation programs of June and August, together with the program of peak irrigation period, July.

In irrigation programming in the model, depletion of 30-45% of the available moisture between permanent wilting point and field capacity was allowed, and the soil moisture was refilled to field capacity at each irrigation. Exceeding the soil moisture depletion level by over 50% was not allowed, as explained by Doorenbos & Kassam (1979).

The extent to which irrigation water requirements of the crops could be met on 6 June, 10 July and 18 August for system rotation periods of 7, 10, 11 and 12 days was determined by running the model. In other words, it was shown by alternative solutions to what level the irrigation water requirements of crops in given periods could be met by system capacity. The length of alternative rotation periods stated above did not cause any problem from the point of view of minimum irrigation intervals of the crops (Kilic & Ozgurel, 2005; Kodal et al., 1997; Sagardoy et al., 1982). However, it was determined that water deficit levels in some canals exceeded 45%, especially in rotation periods which were shorter than necessary. These canals serve a larger area than they can irrigate, because of the unplanned production pattern. In this state, irrigation water requirements of the crops cannot be met completely because of the inadequate carrying capacity of some canals and a shorter length of rotation period than necessary. Summarized results of the MONES 4.1 package are given in Tables 4-6.

As seen in Table 4, water deficits reaching 38.15% (P.7 tertiary) occurred for the 10 day system rotation period in the irrigation applications beginning on 6th June. The maximum levels of water deficit occurring during the 7, 11 and 12 day system rotation periods were 56.31%, 32.10% and 26.05%, respectively. An increase in the length of rotation period diminished the levels of water constraints occurring in the canals. The lengths of these periods were also suitable for minimum irrigation interval of the crops in the research area. However, it is clear that 56.31% water deficiency level occurring in the 7 day system rotation period is not suitable for optimum irrigation and growing conditions of these crops. On the other hand, irrigation water requirements of all 25 tertiaries, except P.7, P.9 and P.26, were met completely during the 12 day system rotation period.

Tertiary name	Total irrigation water requirement (m^3)	Water deficit levels occurring in the length of alternative system rotation periods (%)			
		7 days	10 days	11 days	12 days
P.3	4767.272	0	0	0	0
P.4	28708.209	0	0	0	0
P.5	60016.997	0	0	0	0
P.6	4015.468	0	0	0	0
P.7	39412.259	56.31	38.15	32.10	26.05
P.8	9088.454	0	0	0	0
P.9	30811.573	44.48	21.26	13.51	5.77
P.10	18433.697	6.28	0	0	0
P.11	26643.547	36.01	9.14	0.19	0
P.12	12028.759	0	0	0	0
P.13	22117.774	23.18	0	0	0
P.14	46031.517	26.13	0	0	0
P.15	17683.992	4.25	0	0	0
P.16	57319.330	0	0	0	0
P.17	6567.543	0	0	0	0
P.18	70256.602	0	0	0	0
P.19	83344.510	18.54	0	0	0
P.20	94137.366	0	0	0	0
P.21	26919.283	36.65	10.06	1.20	0
P.22	44876.254	0	0	0	0
P.23	39653.301	0	0	0	0
P.24	40992.809	31.92	3.31	0	0
P.25	8675.461	0	0	0	0
P.26	70853.951	47.18	25.11	17.76	10.40
P.27	3564.963	0	0	0	0
P.28	812.503	0	0	0	0
P.29	1294.043	34.06	6.37	0	0
P.30	19086.784	0	0	0	0

Table 4. Water deficit levels occurring in the alternative rotation periods for the irrigation applications beginning on 6th of June.

July is the peak irrigation period in the district. The results obtained from model solution for the irrigation applications beginning on 10th July are given in Table 5.

As seen in Table 5, 64.91%, 50.43%, 45.61% and 40.78% of maximum water constraints occurred respectively for system rotation periods of 7, 10, 11 and 12 days. It is not suitable for optimum irrigation conditions that water constraint levels occurring in the rotation periods of 7 and 10 days be over 50% (Doorenbos & Kassam, 1979). In other words, high water requirements in some canals cannot be met completely because of the inadequate canal carrying capacity and shorter than necessary length of rotation period. It is clear that a 10 day system rotation period applied in reality in the network caused a yield loss, especially in the peak irrigation period. However, irrigation water requirements of all 25 tertiaries except P.7, P.9 and P.26 were met completely during the 12 day system rotation period.

Tertiary name	Total irrigation water requirement (m^3)	Water deficit levels occurring in the length of alternative system rotation periods (%)			
		7 days	10 days	11 days	12 days
P.3	4908.777	0	0	0	0
P.4	29787.900	0	0	0	0
P.5	58798.374	0	0	0	0
P.6	4147.970	0	0	0	0
P.7	49443.972	64.91	50.43	45.61	40.78
P.8	9229.546	0	0	0	0
P.9	35387.586	51.49	31.27	24.53	17.79
P.10	19003.545	9.05	0	0	0
P.11	27568.383	38.11	12.15	3.49	0
P.12	12696.326	0	0	0	0
P.13	23099.029	26.39	0	0	0
P.14	47988.167	29.08	0	0	0
P.15	18626.505	9.03	0	0	0
P.16	59186.227	0	0	0	0
P.17	6949.991	0	0	0	0
P.18	72267.113	0	0	0	0
P.19	86136.363	21.13	0	0	0
P.20	98793.526	0	0	0	0
P.21	28307.164	39.69	14.41	5.98	0
P.22	46591.310	0	0	0	0
P.23	41744.648	0	0	0	0
P.24	42601.463	34.44	6.91	0	0
P.25	9010.986	0	0	0	0
P.26	73765.516	49.22	28.02	20.95	13.88
P.27	3624.255	0	0	0	0
P.28	868.814	0	0	0	0
P.29	1315.566	35.12	7.88	0	0
P.30	19554.267	0	0	0	0

Table 5. Water deficit levels occurring in the alternative rotation periods for the irrigation applications beginning on 10th of July.

Results obtained by running the model for irrigation period beginning on 18th August are given in Table 6.

Tertiary name	Total irrigation water requirement (m^3)	Water deficit levels occurring in the length of alternative system rotation periods (%)			
		7 days	10 days	11 days	12 days
P.3	4367.812	0	0	0	0
P.4	27970.355	0	0	0	0
P.5	52577.673	0	0	0	0
P.6	3981.409	0	0	0	0
P.7	44672.084	61.30	45.28	39.94	34.60
P.8	8976.829	0	0	0	0
P.9	32689.617	47.60	25.70	18.41	11.12
P.10	16509.593	1.81	0	0	0
P.11	24626.182	30.87	0	0	0
P.12	11958.468	0	0	0	0
P.13	22001.799	22.78	0	0	0
P.14	43465.261	21.84	0	0	0
P.15	17676.586	4.21	0	0	0
P.16	53336.634	0	0	0	0
P.17	6818.113	0	0	0	0
P.18	64475.342	0	0	0	0
P.19	75985.677	10.77	0	0	0
P.20	93733.214	0	0	0	0
P.21	27051.418	36.95	10.49	1.68	0
P.22	43428.077	0	0	0	0
P.23	40029.311	0	0	0	0
P.24	38629.018	27.84	0	0	0
P.25	8779.407	0	0	0	0
P.26	67129.658	44.33	21.03	13.27	5.50
P.27	3520.494	0	0	0	0
P.28	852.726	0	0	0	0
P.29	1277.901	33.25	5.21	0	0
P.30	18020.521	0	0	0	0

Table 6. Water deficit levels occurring in the alternative rotation periods for the irrigation applications beginning on 18th of August.

Maximum levels of water constraints occurring in the system rotation periods of 7, 10, 11 and 12 days were 61.30%, 45.28%, 39.94% and 34.60% respectively in the P.7 tertiary (Table 6). These ratios were lower than the maximum deficiency levels which occurred in the irrigation period beginning on 10th July. However, the water deficiency level (45.28%) which occurred in the 10 day system rotation period which was applied in reality in the research area was quite high. On the other hand, irrigation water requirements of all 25 tertiaries, except P.7, P.9 and P.26 were met completely during the 12 day system rotation period.

4.1 Irrigation water requirements of allocation zones and amounts of water allocated to them in alternative system rotation periods

Allocation of irrigation water in the research area was evaluated at the level of zones. Three different irrigation applications, started on 6 June, 10 July and 18 August, were taken into consideration for the allocation zones, which were served by different canal rotation groups. Irrigation water requirements in tertiaries, length of irrigation times for the canals and water deficit levels occurring in these areas were analyzed for irrigation programs devised for 7, 10, 11 and 12 day alternative system rotation periods. Results were evaluated from the point of view of water use effectiveness at the network level.

The irrigation water requirement of AZ I and the amount of water allocated to this zone during the alternative system rotation periods for the irrigation applications started on 6 June are shown in Figure 7.

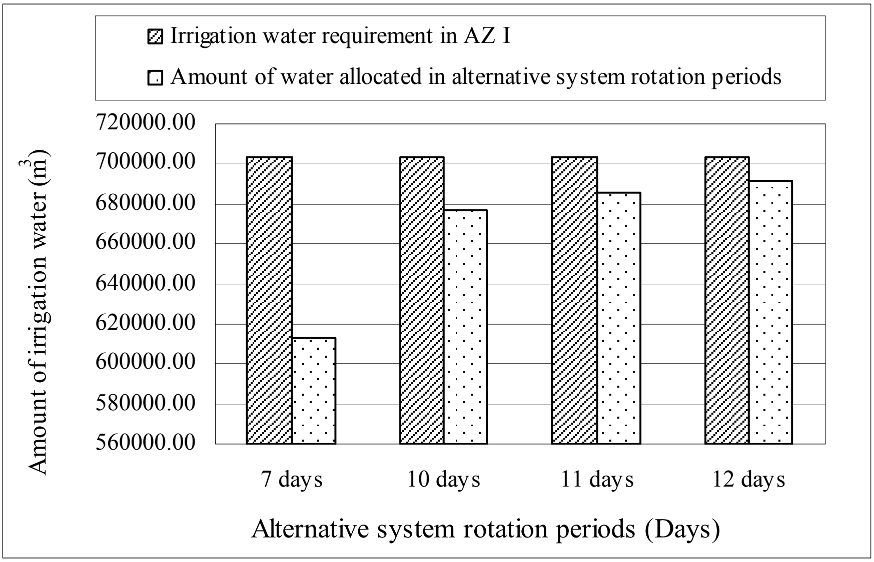

Fig. 7. Irrigation water requirement of AZ I and the amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 6 June.

As seen in Figure 7, as the length of alternative system rotation periods increased, the amount of water delivered to AZ I increased and deficit levels diminished. In the 7 day system rotation period, 95.06 hours of irrigation time were allocated to AZ I for the irrigation application started on 6 June (Table 3). In this process, a 12.78% water deficit occurred in this zone (Figure 7). In contrast, it was seen that 56.31%, 44.48%, 36.01% and 36.65% water deficits occurred in tertiaries P.7, P.9, P.11 and P.21 of AZ I respectively (Table 4).

When the length of the system rotation period was increased to 10 days, 135.80 hours of irrigation time was allocated to AZ I. In this state, the water deficit level in tertiary P.7 took the value of 38.15% (Table 4). In the 11 day system rotation period, the water deficit level decreased to 32.10% in tertiary P.7 (Table 4) for 149.38 hours of irrigation time (Table 3) and a 2.44% water constraint occurred in AZ I (Figure 7). As a result, most of the irrigation water requirement of AZ I was met in the 11 day system rotation period. Therefore, it was decided that the 11 day rotation period was suitable for AZ I in the irrigation applications started on 6 June.

The irrigation water requirement of AZ II and the amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 6 June are shown in Figure 8.

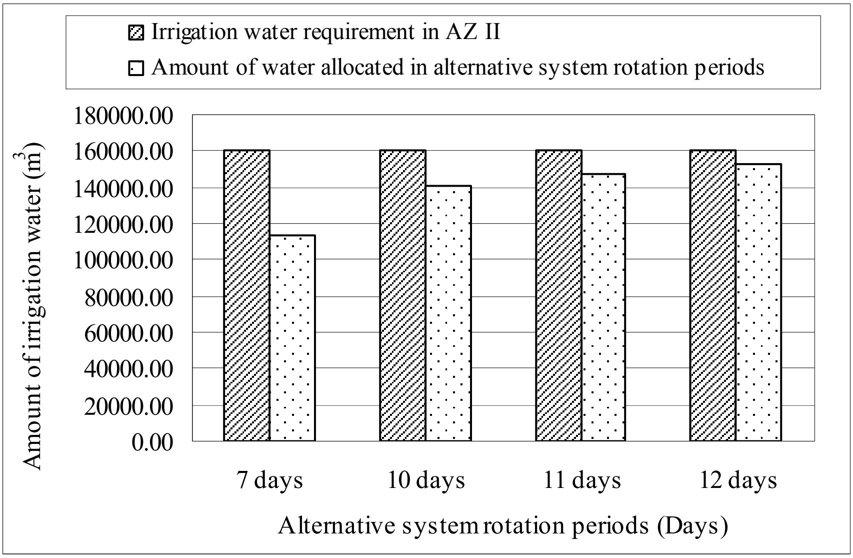

Fig. 8. Irrigation water requirement of AZ II and amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 6 June.

In this period, 51.93 hours, 74.18 hours, 81.60 hours and 89.02 hours of irrigation time were allocated to AZ II in 7, 10, 11 and 12 day alternative system rotation periods respectively (Table 3). A 29.04% water constraint occurred in AZ II for the 7 day system rotation period (Figure 8). However, if water deficits are analyzed at tertiary level for this period, it is seen that 31.92% and 47.18% water deficits occur in canals P.24 and P.26 respectively (Table 4). In other words, water deficits occurring in these tertiaries were higher than the deficit level of AZ II. The reason for this is that some of the canals serve larger areas than they should.

As seen in Figure 8, water deficits in AZ II showed a diminishing trend in the 10, 11 and 12 day system rotation periods, taking the values of 11.95%, 7.86% and 4.60% respectively. Although the water constraint level was 11.95% in AZ II in the 10 day system rotation period for the irrigation applications started on 6 June, a high (38.15%) level of deficit occurred in tertiary P.7 in AZ I in the same period. This made the 11 day system rotation period suitable for AZ II also.

The irrigation water requirement of AZ III and the amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 6 June are shown in Figure 9.

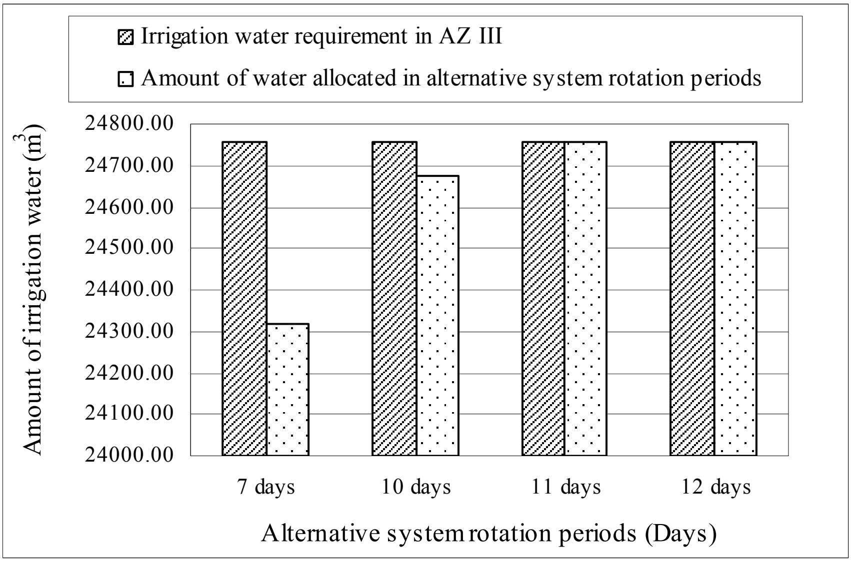

Fig. 9. Irrigation water requirement of AZ III and amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 6 June.

In irrigation applications started on 6 June, 21.01 hours and 30.02 hours of irrigation time were allocated to AZ III in the 7 and 10 day alternative system rotation periods (Table 3). As the hydraulic features of the canals in this zone were suitable for water requirements of the crop pattern and size of the irrigated area, most of the water requirements were met in this command. In the 7 and 10 day system rotation periods, 1.78% and 0.33% water deficits occurred respectively in AZ III. No water constraint occurred in the 33.02 hours of irrigation time allocated for the 11 day system rotation period in the same zone. In addition, it was a desired condition from the point of view of irrigation programming that the 11 day system rotation period was also suitable for AZ I and AZ II, and that no water constraint occurred in AZ III for this period. As a result, an 11 day system rotation period and 149.38 hours, 81.60 hours and 33.02 hours maximum irrigation times allocated to AZ I, AZ II and AZ III respectively for the irrigation applications started on 6 June were found to be suitable.

The irrigation water requirement of AZ I and the amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 10 July are shown in Figure 10.

In irrigation applications started on 10 July, which is in the peak period in the research area, a 15.39% water deficit occurred in AZ I during the 7 day system rotation period (Figure 10). In contrast, the water deficit at tertiary level in this zone increased depending on the rising irrigation water requirements in the peak period. High levels of water constraint (64.91%, 51.49%, 38.11% and 39.69%) occurred in the commands of tertiaries P.7, P.9, P.11 and P.21 respectively during the 7 day system rotation period (Table 5).

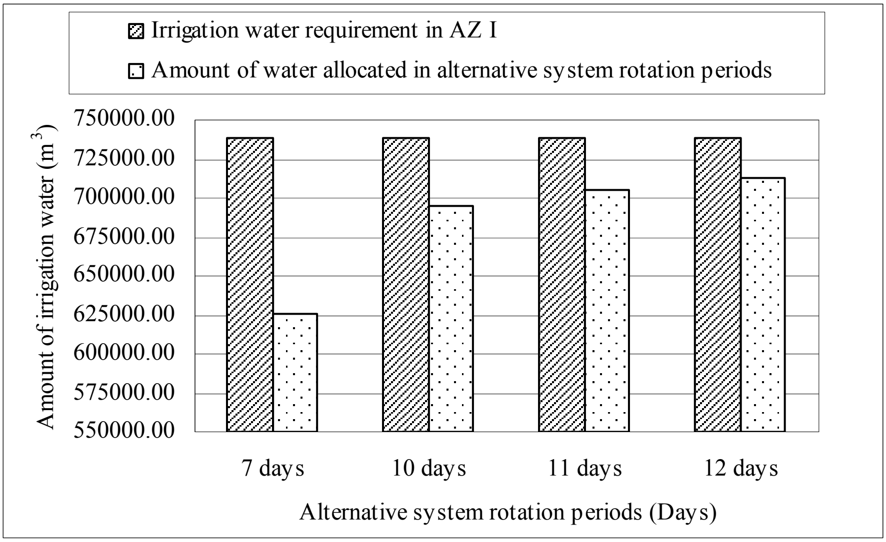

Fig. 10. Irrigation water requirement of AZ I and amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 10 July.

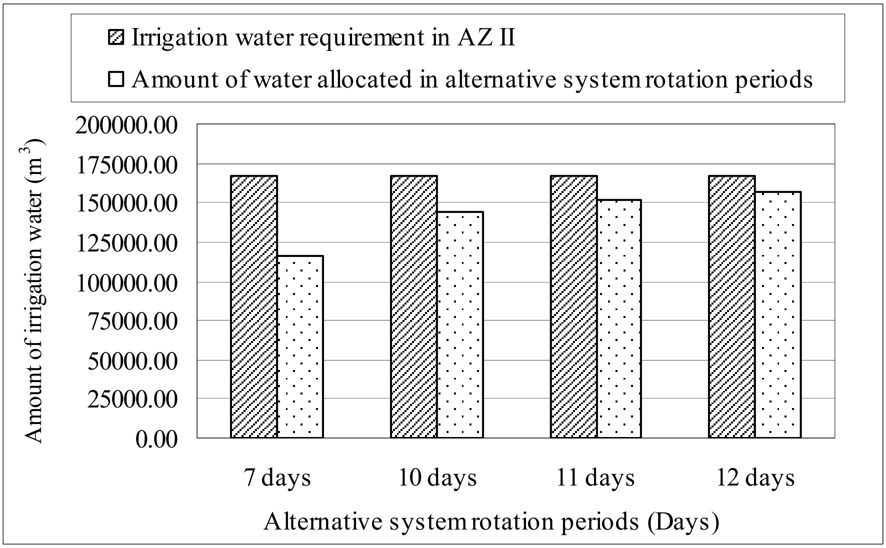

Fig. 11. Irrigation water requirement of AZ II and amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 10 July.

Although a low water deficit of 5.88% occurred in AZ I in the 10 day system rotation period, a fairly high level of water constraint (50.43%) occurred in tertiary P.7 in the same zone. Also, a water deficit of 4.59% occurred in AZ I in the 11 day system rotation period;

however, a 45.61% water constraint continued its effect in tertiary P.7. As these irrigation applications were in the peak period, the water requirements of the crops increased, and water constraint levels in the tertiaries also rose. As the water constraint decreased to 3.58% in AZ I for the 12 day system rotation period, the deficit level in the command of tertiary P.7 also diminished to 40.78%. Thus, the 12 day system rotation period was suitable in AZ I for the irrigation applications started on 10 July.

The irrigation water requirement of AZ II and the amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 10 July are shown in Figure 11.

In irrigation applications started on 10 July, 51.93 hours of irrigation time was allocated to AZ II for the 7 day system rotation period (Table 3), and a 30.50% water deficit occurred in this zone (Figure 11). In this period, a high (49.22%) level of water deficit, which occurred in tertiary P.26 in AZ II, caused an increment of the water constraint level for the entire zone. 14.13%, 9.25% and 6.13% water constraints occurred in the 10, 11 and 12 day alternative system rotation periods respectively in AZ II. As seen on Figure 11, as the length of the alternative system rotation periods increased, water constraint levels showed a decreasing trend in this zone. Thus, the 12 day system rotation period was found to be suitable in AZ II for irrigation applications started on 10 July, owing to the fact that this rotation period was also suitable for AZ I, and that the lowest water constraint occurred in AZ II with a ratio of 6.13% in this period.

The irrigation water requirement of AZ III and the amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 10 July are shown in Figure 12.

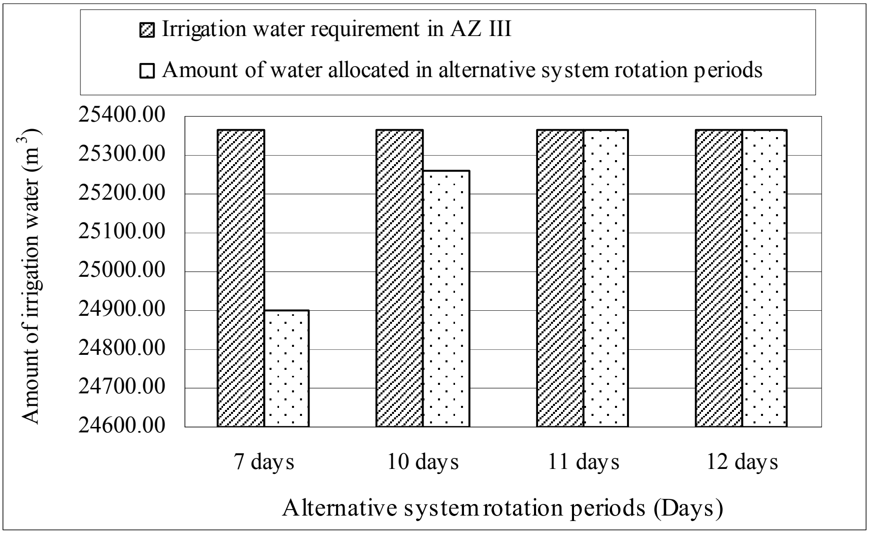

Fig. 12. Irrigation water requirement of AZ III and amount of water allocated to this zone during the alternative system rotation periods in irrigation applications started on 10 July.

In the 7 and 10 day system rotation periods, 1.81% and 0.41% water deficits occurred in AZ III. No constraint occurred in AZ III for the 11 and 12 day rotation periods (Figure 12). Since the water carrying capacities of the canals were adequate for the size of the irrigated area and the water requirements of the crops in this zone, most of the requirements were met in that district. Thus, 12 day system rotation period was found to be suitable for the entire district containing three of the zones for the irrigation applications started on 10 July, which was in the peak period.

The irrigation water requirement of AZ I and the amount of water allocated to this zone during the alternative system rotation periods for the irrigation applications started on 18 August are given in Figure 13.

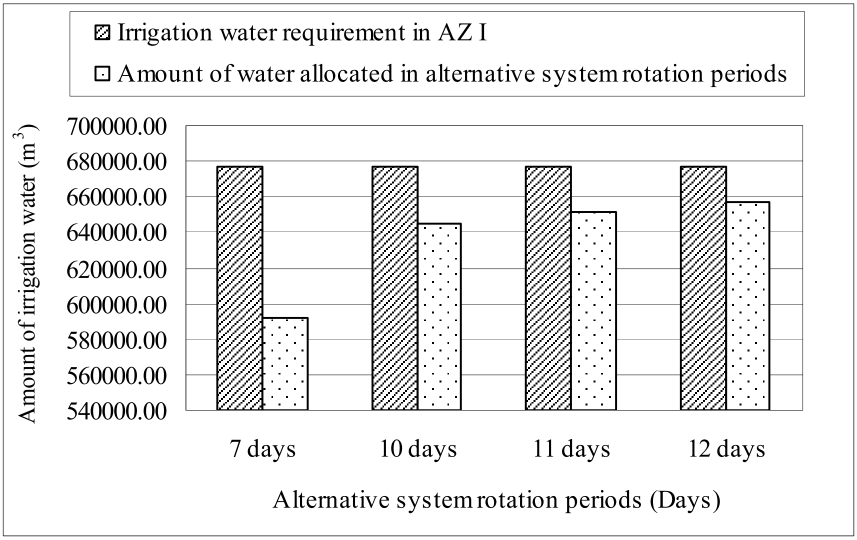

Fig. 13. Irrigation water requirement of AZ I and amount of water allocated to this zone during the alternative system rotation periods for the irrigation applications started on 18 August.

In irrigation applications started on 18 August in the research area, 12.42%, 4.70%, 3.60% and 2.82% water deficits occurred in AZ I for the 7, 10, 11 and 12 day alternative system rotation periods respectively (Figure 13). In addition , a high level of water constraint occurred in some tertiaries in AZ I.

In the 7 day system rotation period, 95.06 hours of irrigation time were allocated to AZ I (Table 3). During this process, 61.30%, 47.60% and 36.95% water deficits occurred in tertiaries P.7, P.9 and P.21 respectively (Table 6). For the 10 day system rotation period, 135.80 hours of irrigation time was allocated to AZ I, and a 45.28% water deficit occurred in tertiary P.7. When 149.38 hours of irrigation time was allocated to this zone in the 11 day system rotation period in order to reduce the water constraint in this canal (Table 3), the deficit level diminished to 39.94% in tertiary P.7 (Table 6). Since no constraint occurred in most of the canals in AZ I, the 11 day system rotation period was found to be suitable for this zone in this period.

The irrigation water requirements of AZ II and the amount of water allocated to this zone during the alternative system rotation periods for irrigation applications started on 18 August are shown in Figure 14.

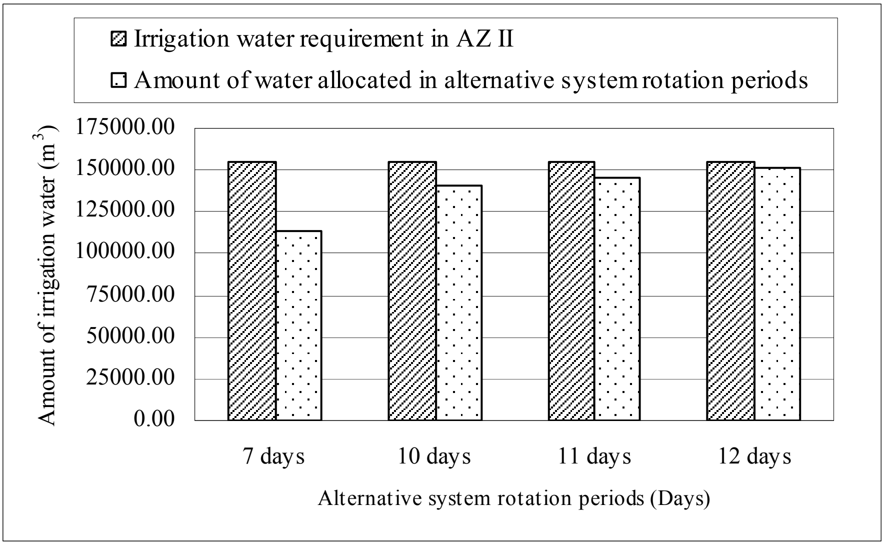

Fig. 14. Irrigation water requirements of AZ II and amount of water allocated to this zone during the alternative system rotation periods for irrigation applications started on 18 August.

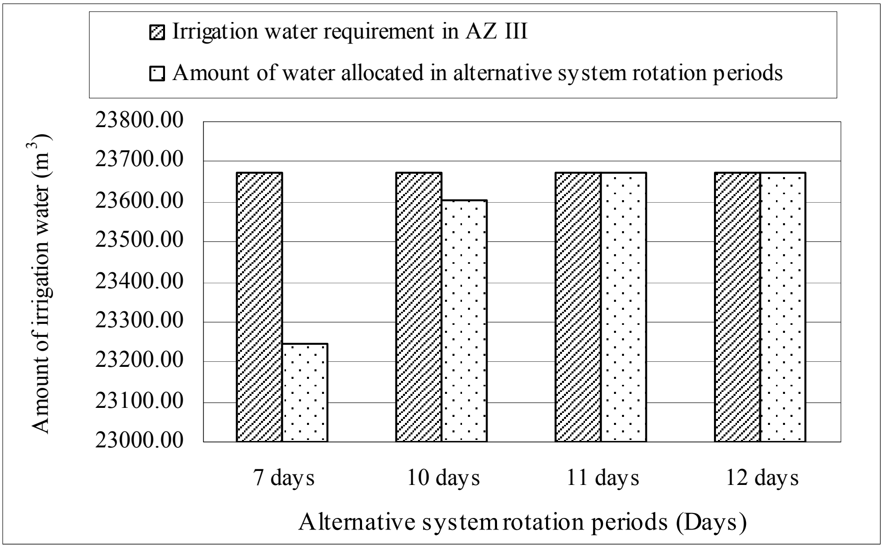

Fig. 15. Irrigation water requirements of AZ III and amount of water allocated to this zone during the alternative system rotation periods for irrigation applications started on 18 August.

In the irrigation applications started on 18 August, 51.93 hours and 74.18 hours of irrigation time were allocated to AZ II in the 7 and 10 day system rotation periods (Table 3), also 26.21% and 9.13% water constraints occurred in AZ II in these rotation periods respectively (Figure 14). A 44.33% water constraint occurred in tertiary P.26 in the 7 day system rotation period. This deficit level fell to 21.03% in the 10 day rotation period (Table 6). On the other hand, since the 11 day system rotation period was suitable for AZ I and nearly 71% of the tertiaries serving the entire district were in AZ I, these conditions affected the rotation period of AZ II, and 11 days were found suitable for this zone in this irrigation period.

Irrigation water requirements of AZ III and the amount of water allocated to this zone during the alternative system rotation periods for irrigation applications started on 18 August are shown in Figure 15.

In this period, 1.79% and 0.28% water deficits occurred in the 7 and 10 day system rotation periods respectively in AZ III. No water constraint occurred in the 11 day rotation period in this zone (Figure 15).

As a result, the 11 day system rotation period was found to be suitable for irrigation applications started on 18 August, and 149.38 hours, 81.60 hours and 33.02 hours maximum irrigation times were allocated to AZ I, AZ II and AZ III respectively.

5. Conclusions

In this investigation, irrigation programming model MONES 4.1 (Kilic, 2010) was applied to Sector VII in the Right Bank Irrigation System of Ahmetli Regulator in the Lower Gediz Basin, Turkey. Irrigation programs were devised for different growing stages and irrigation periods of the crops in the research area for 7, 10, 11 and 12 day system rotation periods.

Considerable differences occurred between the water allocation plan applied in the research area in reality and the model results, from the points of view of irrigation programs, canal rotation system, water allocation zones and deficit levels occurring in canals with different lengths of rotation periods. During the 10 day system rotation period which was applied in reality in the research area, all the tertiaries were kept open, no canal rotation program was applied on the network, and the irrigation area was not divided into different allocation zones in reality by the irrigation association. However, maximum water carrying capacity of the secondary canal serving Sector VII was inadequate for distribution of water to all tertiaries at the same time (Kilic, 2004; Kilic & Tuylu, 2010). Because of this, the tertiary canals in the network could not be operated at their maximum capacities according to the water allocation plan in reality.

In addition, for the 7 and 10 day system rotation periods, deficit levels exceeded 45% in some canals, because the lengths of these periods were not suitable for the infrastructure of the system, the hydraulic features of the canals, and the actual production pattern. As a result, it was not possible to irrigate the whole area during the 7 and 10 day system rotation periods.

In order to operate the system at the optimum level, the research area must be divided into allocation zones by running the entire network at maximum capacity. In order to achieve this, the canal rotation groups which are most suitable for the system must be determined.

In addition, irrigation water requirements of the crops grown in the district must be estimated in a scientific way for different growing stages. In this way, the amount of irrigation water to be allocated from the resource to the allocation zones in different periods can be determined accurately.

Whatever the location of a plot in the network, the capacity of the canal receiving water from the system, or the water conveyance efficiency, this plot must benefit from the water resource and system equally in temporal and spatial dimensions. In this process, the optimum length of irrigation time must be determined for each allocation zone by taking into consideration such parameters as the infrastructure of the network, the hydraulic features of the canals, the water conveyance efficiency, the soil features of the district, the location and size of the plots, the plant pattern, and the irrigation water requirements of the crops. Since there are a large number of water users in the system, irrigation applications must be monitored continuously by the technical personnel of the association. All these processes should be carried out serially with the aid of computers in real time conditions.

Apart from this, maintenance, repair, renovation and cleaning activities in the network must be performed regularly by the association, because these processes have a direct effect on to the irrigation programming and allocation of water at network level.

The most important point is that decision support systems enabling real time irrigation programming at network level should be used in order to obtain the optimum benefit per unit amount of deficit resources.

The MONES 4.1 model enabled operation of the system at maximum capacity by dividing the research area into three different allocation zones by taking into consideration the parameters stated above. Also, the most suitable length of system rotation periods according to the model solution was determined to be 11 days for June and August, and 12 days for the peak irrigation period in July. For the irrigation applications started on 6 June and 18 August, 149.38 hours, 81.60 hours and 33.02 hours maximum irrigation times allocated to AZ I, AZ II and AZ III respectively were found to be suitable. In irrigation applications started on 6 June, 2.44% and 7.86% water deficits occurred in AZ I and AZ II respectively. No water constraint occurred in AZ III in this period. In addition, 162.96 hours, 89.02 hours and 36.02 hours maximum irrigation times were allocated to AZ I, AZ II and AZ III respectively for the irrigation applications started on 10 July in the peak period. Also, while 3.58% and 6.13% water deficits occurred in AZ I and AZ II respectively, no water constraint occurred in AZ III in this period. For the irrigation applications started on 18 August, 3.60% and 5.76% water constraints occurred in AZ I and AZ II. On the other hand, no water deficit occurred in AZ III in this period. Since the water-carrying capacities of the canals were adequate for the size of the irrigated area and the water requirements of the crops in AZ III, most of the requirements could be met in that district in different irrigation periods.

As a result, it can be seen that the application of irrigation programming techniques to such systems has a vital importance both for optimum operation of the system and for the sustainability of deficit resources.

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Part 2

Climate Change Mitigation and Adaptation

4

Sustainable Use of Natural Resources of Dryland Regions in Controlling of Environmental Degradation and Desertification

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1. Introduction

One-half of the world's countries have portions or all of their land areas in hyper-arid, arid, or semi-arid climatological zones. These lands together with their sub-humid margins and savannas cover nearly 45 million square kilometers or approximately 30 percent of the earth's land surface. These lands collectively comprise the dryland regions of the world where severe ecological degradation and desertification is occurring at alarming rates and threatening the livelihoods of over 900 million inhabitants (Middleton & Thomas, 1997; Mainguet, 1999; Altschul 2008). Applications of carefully planned land-use practices can often halt and eventually reverse the processes of environmental degradation and desertification on these landscapes. Importantly, the formulation and application of these interventions must be based on sound technical knowledge, the interrelationships of human, ecological, and socio-economic factors, and responsive policy options. One problem, however, is that many planners, managers, and policy-makers have often considered the drylands regions as wastelands and, therefore, do not appreciate their critical environmental role and potential contributions to the welfare of people.

The chapter reviews the land-use issues, assesses the weaknesses, and reviews the options available for the conservation and sustainable use of natural resources in the dryland regions of the world. The information presented is based largely on publications and office reports of the past 35 years. After the general features of dryland environments and how people use their natural resources are discussed, challenges to the sustainable use of natural resources are considered. The close correlation between the dryland regions of the world and the occurrence of environmental degradation and desertification is then indicated. Finally, polices necessary to sustain the use of land and natural resources while controlling environmental degradation and desertification including strategies for policy implementation are described.

2. General features of dryland environments

Dryland environments are characterized by wide differences in temperatures, inadequate and unreliable rainfall events, seasons when rain falls, and frequent conditions of aridity. Some of these environments have excessive heat while others are cold and dry areas.

Extremes in temperature ranging from lows approaching 0°C to highs exceeding 50°C at times are characteristic of these environments ((Middleton & Thomas, 1997; Mainguet, 1999; Altschul 2008). The limited rainfall amounts are compounded by high evapotranspiration rates that cause water shortages in many dryland regions. Varying degrees of aridity is a climatic condition that can be expected. Unexpected but recurring droughts add uncertainty to the lives of people as a consequence.

2.1 Geomorphic features and soils

Mountain massifs, plains, pediments, and incised ravines and drainage patterns result in sharp changes in slope and topography and a high degree of angularity. Rivers generally traverse wide floodplains at lower elevations and at times are subject to dramatic changes in drainage patterns. Many landforms in the more arid climates are partially covered by unstable sand dunes or sand sheets that can impact livestock grazing lands, agricultural crops, and cities and villages. Other geomorphic features influence the formation and characteristics of the soils including the distributions of coarse and fine soil fractions from transportation processes, reworking and disposition by wind and water, and periodic inundation of floodplains (Middleton & Thomas, 1997; Mainguet, 1999; Altschul 2008)). Among the beneficial effects of these influences, however, are a replenishment of soil nutrients and leaching of accumulated salts in the soil. Of primary importance of the soils is their water-holding capacity and ability to supply nutrients. Depth of the soil governs the amount of water stored in a profile. Depth of the soils is often limited by a hardpan layer, however, restricting water-holding capacities. Many soils are characterized by the leaching of nutrients and intensive weathering of minerals. Soil fertility, therefore, is low.

2.2 Water

Most of the water is found in large rivers that originate in higher elevations. These river systems include the Nile in the Sudan and Egypt and the Tigris, Indus, Ganges, Senegal, and Niger. Tributaries to these rivers are likely to be intermittent or ephemeral in contrast to the perennial flows of smaller streams in other temperate and moist tropical regions. The flow of intermittent or ephemeral streams is almost exclusively dependent on precipitation events that determined the duration and amount of channel flow. The tendency for the channel beds to reside above a groundwater table so that channel flows lose water to the groundwater is another reason for the intermittent or ephemeral flows of streams (Middleton & Thomas, 1997; Mainguet, 1999; Altschul 2008). Evapotranspiration processes and the infiltration of the flowing water into the channel beds can diminish the volume of water in the streams as they flow to lower elevations.

Local but limited groundwater is often available to support the ecological development of relatively small areas. However, the recharge of groundwater resources is dependent on the amount, intensity, and duration of the infrequent rainfall and soil properties including infiltrations capacities and water-holding characteristics of the soils that also influence the amount of surface runoff on an area (Altschul 2008). Construction of wells is necessary to have access the groundwater resources.

Water available for people's use in many dryland regions can be affected to varying magnitudes by salinity (Mainguet, 1999). Problems of salinity are more widespread and acute in the drylands than in other temperate and moist tropical regions.

2.3 Plants

Most plants possess adaptations that enable them to successfully reproduce, sustain their growth, and survive in some of the harshest environments in the world. Some plants have evolved special root systems while others have unique leaf characteristics that allow them to withstand prolonged periods of drought. Other plants lose their leaves when soil moisture conditions become too dry to support their survival. Ephemeral annuals, succulent perennials, and non-succulent perennials are found throughout dryland environments (Middleton & Thomas, 1997; Mainguet, 1999; Altschul 2008). Ephemeral annuals appear after rains, complete their life cycle in a short growing season and at times form dense stands to provide limited forage for livestock. Succulent perennials store water through the enlargement of parenchymal tissue and their low rates of transpiration. Cacti are typical of the succulent perennials. Non-succulent perennials that withstand the stress of dryland environments are the majority of plants in these regions. Three forms of non-succulent perennials are found. Evergreen plants are active biologically throughout the year, drought-deciduous plants are dormant in the dry season, and cold-deciduous plants are dormant in the cold season.

2.4 People

Almost 40 percent of the world's people live in the dryland regions of the world (Altschul, 2008). These people are grouped broadly into nomadic, semi-nomadic, transhumant, and sedentary populations (Child et al. , 1987; Squires & Sidahmed, 1998; Tunstall et al. , 2002). Nomadic people are pastoral groups that depend mostly on livestock for subsistence with small-scale rain-fed farming when possible as a supplement. Nomads migrate in patterns determined by available forage conditions, water availability, and access rules worked out with other pastoral or sedentary groups of people. Semi-nomadic people are also found in pastoral groups that depend mostly on livestock for their livelihood. However, this group of people might also practice agricultural cultivation at base camps where they return for varying periods of time. Transhumant populations combine farming and livestock production during favorable seasons but seasonally migrate along regular routes when grazing diminishes near their farming area. Sedentary farmers practice rain-fed or irrigated agriculture. Land uses are often a combination of agricultural crop, livestock, and occasional wood production.

3. How people use their natural resources

Demands are increasing greatly for food, water, and other natural resources found in the dryland regions as a result of the increasing populations of people. Shortages in these critical resources continue as witnessed by widespread food shortages, lack of potable water, and a loss of livestock grazing lands and deficiency of firewood in many countries. In responding to these increasing demands, people are frequently forced to intensify their use of these limited natural resources and, as a consequence, degrade the impacted ecosystems in doing so. Such actions are a leading cause of environmental degradation and desertification. It is unfortunate that the ways in which people use the natural resources of dryland regions are not normally well defined and often based on historical but inappropriate cultural practices. How people use the resources available to them are generally centered on pastoralism, small-scale agricultural crop production, forestry-related activities, agroforestry practices, and wildlife.

3.1 Pastoralism

Unconfined livestock production has been widespread in the dryland regions of many countries and undoubtedly will continue as such into the future. However, severe environmental degradation and desertification can be accelerated where excessive consumption of the sparse forage resources of often low nutritive value occurs. Changes in the livestock grazing practices on the degraded lands have been and continue to be recommended by technical personnel (Pratt & Gwynne, 1977; Walker, 1979; Child et al. , 1987; Squires & Sidahmed, 1998). However, these suggested changes must be acceptable to the herdsmen' way of life. It is also important that the livestock grazing practices are compatible with other land uses such as agricultural crop production and the use of wood for local needs.

Systems of livestock management practiced in the dryland regions include sedentary, transhumance, and nomadic (Child et al. , 1987; Squires & Sidahmed, 1998). Livestock are kept at a permanent site throughout the year with a sedentary system of grazing. The number of animals is limited to the capacity of the site to support the livestock when the dry season occurs. Should this number be exceeded, the surplus livestock are often placed in the care of a migratory herdsman of the owner's family or a nomadic tribe. The transhumance system also has a permanent base but the number of livestock and environmental conditions are such that a portion of the annual forage requirement is likely to be obtained elsewhere. There are no permanent settlements in the nomadic system because the herdsmen move freely in search of available forage for their livestock. Changing environmental conditions of a locale can induce the individual herdsmen to change from one management system to another for the short-term.

3.2 Small-scale agricultural crop production

Small-scale rain-fed agricultural crop production is practiced on the sites favorable to this type of land use. Exceptions occur where irrigation is possible in which case larger-scale and more intensive agriculture is practiced. Cereals, legumes, and roots are grown as a source of food for people. Annual and perennial grasses and other forage plants for livestock are also grown as agricultural crops but their production is not as commonly stressed as the food for people (Spedding, 1988; Okigbo, 1991; Seckler, 1993). Sedentary agriculture is practiced where soil fertility and precipitation and temperature regimes allow crops to be grown in place. Otherwise, shifting cultivation is practiced where a farmer shifts to other pieces of land once the potentials of the soil to produce agricultural crops on the original land have been lost.

Subsistence and occasionally commercial farming is found in dryland environments. With subsistence farming, most of the crops are produced to meet the immediate needs of families. When a surplus becomes available, the farmers often enter markets to obtain additional incomes. Commercial farming requires infrastructures of roads and vehicles for transportation and the presence of structured marketplaces. Large-scale commercial farming is rarely possible in dryland regions without large irrigations systems.

3.3 Forestry-related activities

Implementation of traditional forestry practices is not generally feasible in the dryland regions of the world with the exception of establishing energy plantations to alleviate the frequently encountered and continuing shortages of firewood in many countries. Implementation of other forestry-related activities in these countries differs in many ways from forestry as it is practiced in more humid ecosystems (Salem, 1988; Wiersum, 1988; Sharma, 1992; Ffolliott et al., 1995a). The applications of forestry-related activities in the dryland regions are broader in scope including producing wood for fuel, poles, and local housing materials; practicing horticulture for a wide range of commercial and subsistence products; managing trees and shrubs as fodder for livestock production; implementing practices that modify microclimates to increase agricultural crop production such as windbreak plantings; and protecting of lands that are susceptible to water and wind erosion.

People often combine their uses of trees and shrubs into combinations of land and natural resources use that are linked to their needs and social values. Therefore, what is commonly called "Dryland Forestry" is more generally defined as the management of trees and shrubs to improve the livelihood and quality of life of people living in dryland environments (Salem, 1988; Ffolliott et al. , 1995a; Hoekstra & Shachak, 1999).

3.4 Agroforestry

While intensive forestry practices are not commonly implemented in dryland regions, agroforestry is practiced widely to sustain the livelihood of rural people. Agroforestry practices involve the deliberate association of trees and shrubs with the production of agricultural crops, livestock grazing, or other components of a land-use system in varying combinations (Nair, 1989; MacDicken & Vergara, 1990; Gordon & Newman, 1997). The general types of agroforestry found in dryland regions are agrosilvicultural practices in which agricultural crop production is combined with forestry-related activities; silvopastoral practices consisting of combinations of forestry-related activities and livestock production; and agrosilvopastoral practices involving varying combinations of agricultural crop production, forestry-related activities, and livestock production.

Regardless of how it is practiced, however, the purpose of agroforestry is to increase the yields and qualities of food production; attain ecological stability on the landscape; obtain more efficient use of natural resources such as utilizing solar radiation inputs more efficiently by the several vegetative layers of most practices and increasing the cycling of nutrients by different depths of rooting systems of the plants.

However, there are limitations to overcome for agroforestry practices to be successful. For example, there can be competition of trees and shrubs with food crops and forage species for sunlight, soil moisture, and nutrients that can reduce the yields of the food crops or forage species (Nair, 1989; Gordon & Newman, 1997). A possibility of the trees and shrubs becoming hosts for insects and diseases harmful to food crops and forage species can be a concern. Perhaps the greatest limitation to agroforestry is the often encountered resistance by farmers to displacing food crops and forage resources with trees and shrubs where land is scarce.

3.5 Wildlife

Wildlife species are often vital to the well-being of many people because they provide meat, skins, and other values. Some of wildlife species are superior to domesticated livestock in their adaptive physiological character, resistance to disease, and general capabilities to survive on marginal diets. In addition, many wildlife species are exploited commercially in a variety of ways (Pratt & Gwynne, 1977; Child et al. , 1987; Hoekstra & Shachak 1999). It is also true that some of these species contribute little to people's substances. To the extent possible, therefore, it is necessary to reconcile the conflicting values of wildlife and the development of more holistic land-use strategies.

Wildlife ranching has become a profitable enterprise in many dryland regions of the world. Wildlife ranching typically involves fee hunting for sport or raising indigenous species for the production of meat and other products (Pratt & Gwynne, 1977; Hopcraft, 1990). The economic returns from hunting can exceed those from solely livestock production in some localities. Mixed wildlife and livestock ranching has also been profitable in the countries of eastern Africa.

4. Challenges to sustainable use of natural resources

Achieving the sustainable use of natural resources is a challenge to planners, managers, and policy-makers because of the inherent scarcity of water, the fragile nature of the ecosystems, and the increasing pressures of enlarging human and livestock populations in many dryland regions of the world. Recognition of these limitations is a first step in creating a policy framework that will lead to the sustained uses of natural resources and while controlling the process of environmental degradation of these ecosystems. These limitations generally manifest themselves in terms of water scarcity, continuing land degradation and desertification, and socio-economic and demographic changes.

4.1 Water scarcity

Availability of reliable water sources is always problematic in dryland environments and, furthermore, its sustainability continues to be jeopardized by the demands for potable water increasing at alarming rates over large areas. The stability of available water resources is also crucial to the control degradation and combat desertification. While water scarcity is caused largely by its unequal distribution, it also results from its pollution that makes available water supplies unusable. However, many efforts to develop water resources have focused on increasing available supplies and solving the problem of distribution (Thomas et al. , 1993; Postel, 1997; Grey & Sadoff, 2006; Gregersen et al. , 2007). Unfortunately, this orientation has resulted in unwanted side effects that have economic, social, political, and environmental implications in many instances. For example, the applications of innovated technologies such as desalination are energy intensive that has both economic and environmental impacts. As a consequence, water resource problems and some of the solutions to these problems have adversely affected the health and wealth of people with the greatest threats occurring in the poorest of countries.

Because agriculture is the major user of freshwater resources worldwide, intensified efforts need to be directed toward reducing the agricultural uses of water (Thomas et al. , 1993; Gregersen et al. , 2007). Providing reliable supplies of water for uses other than agriculture, therefore, can be essential to people's well-being. Securing water supplies and protecting them from contamination are not simply technical problems to be solved with technical solutions but also institutional and political issues. However, effective institutional and political resources for managing water resources are frequently limited. As a consequence, the water resources in many countries with dryland environments continue to be administered in a mode of crisis with governments reacting only when droughts, water pollution, or flooding occur.

4.2 Continuing land degradation and desertification

Rapidly spreading environmental degradation and desertification of dryland ecosystems is a problem of worldwide dimensions. To illustrate this point, a study by the United Nations Environment Programme found that an area the size of the People's Republic of China and India combined had suffered moderate to extreme soil degradation caused mainly by inappropriate agricultural practices, on-going deforestation activities, and overgrazing of livestock by the early 1990s (World Resources Institute, 1992). This degradation represented 1. 2 billion hectares or almost 12 percent of the earth surface. Soil degradation in Africa and Asia is also caused by nutrient losses on land that is used for low-input agriculture and the effects of salinization resulting from poor management of irrigation systems (Chandra & Bhatia, 2000). Continuing losses of limited soil resources by wind erosion are also widespread on throughout the dryland regions of the world.

The continuing loss of forests, woodlands, and rangelands also contributes to environmental degradation and desertification processes of already fragile watershed landscapes as the hydrologic functions of these landscapes are diminished or even destroyed. A consequence of the losses of these ecosystems can lead to downstream flooding and the transport of excessive sediment loads and other pollutants into reservoirs. These impacts can be felt within a river basin, throughout a country, and even in neighboring countries sharing a common river basin (Sharma, 1992; Brooks et al. , 2003; Gregersen et al. , 2007).

Establishment of introduced or invasive species caused by the ecosystem alterations resulting from environmental degradation and desertification is also common. These often unwanted species can lead to a decrease in the biological diversity of flora and fauna that further weakens the ability of marginal lands to maintain the capacity of natural resources (McNeely et al. , 1990; Hoekstra & Shachak, 1999). While tropical rainforests receive more international attention with respect to the loss of species richness, dryland regions also have high levels of endemism of plant and animal species and, therefore, are often in more urgent need of protection and conservation. All of these causes of degradation are likely to increase in importance in the future because of population increases.

Environmental degradation and desertification are likely to take place in ecosystems that are less able to recover from environmental stresses than other temperate and moist tropical ecosystems. Many of these landscapes are already severely degraded to point of desertification or threatened by desertification processes. India, Pakistan, Bangladesh, Ethiopia, Kenya, and the Sahelian-Sudanian regions of West Africa have large areas of already severely degraded or desertified with significant areas moving in that direction (Dregne, 1098; United Nations Environment Programme, 1992; Hoekstra & Shachak 1999).

4.3 Socio-economic and demographic changes

Understanding the socio-economic issues unique to the dryland regions is fundamental to planning and implementing land-use strategies and management practices and formulating effective policies that promote the sustainable use of natural resources on lands threatened by degradation and desertification. As dryland ecosystems are inherently marginal in their natural character, the socio-economic and demographic status of the inhabitants of these ecosystems differs from that of people living other regions of the world with richer and more abundant endowments of natural resources (Whitehead et al. , 1988; Hoekstra & Shachak, 1999). People living in dryland regions face constant risks to their well-being due to the harsh environment conditions that they continually confront. These prevailing conditions can limit income generation and employment opportunities.

Many inhabitants are dependent on traditional subsistence practices that are often centered on raising livestock. These pastoral economies are closely adapted to their environments (Child et al. 1987; Squires & Sidahmed, 1998). For example, there is often a high economic dependence on the exchange of livestock and livestock products (milk, ghee, hides, horns) that are supplemented by agriculture produce wherever possible and the exchange of minor tree products (incense, gums, resins, beeswax) and minerals and gems (amber, crystals, mica).

Low population densities, low land-to-human ratios, and the high mobility of rural people and their livestock are also characteristic of the dryland regions of the world. These population characteristics and the mobility of people make it difficult for central governments to effectively provide education, extension services, or health care; or collect taxes, combat crime, or enforce policies and regulations affecting the use of land and natural resources. To compound these difficulties, rural people are often discriminated against because of their marginalized economic, ethnic, or cultural differences.

Many of these rural people are organized into societies within historical systems of trade, tenure relations, and social exchange. However, for example, the established rules of access to livestock water sources can be exceedingly complex and are typically supported by traditional systems for resource management and conflict resolution (Squires & Sidahmed, 1998). This complexity is not surprising because of the high degree of competition among social groups for the same resources of land and water. The traditional rights to water and forage resources in some countries are based on Ottoman or Islamic laws that in the eyes of the affected people take precedence over national laws. These traditional systems are currently breaking down in many areas due to increased population growth and increased commercialization of traditional grazing lands and the herding of livestock in some countries.

5. Environmental degradation and desertification

Many authorities agree that environmental degradation and desertification are attributed to overgrazing by livestock, improper cultivation of agricultural crops, deforestation, or combinations of these and other causes (Anderson & Fishwick, 1984; Repetto, 1988; Whitehead et al. , 1988; Food and Agriculture Organization of the United Nations, 1989; Weber, 1989; El-Baz, 1991; Mouat & Hutchinson, 1995; Hoekstra & Shachak, 1999). Desertification is a special issue of critical concern in the dryland regions of the world. The United Nations Environment Programme has estimated that approximately 35 million square kilometers of the dryland regions of the world, an area approximately the size of both North and South America, are already desertified or affected by desertification processes. Equally important is the fact that nearly 30,000 square kilometers of land are reduced to a state of uselessness every year.

A map of the dryland regions of the world (Dregne, 1983), when compared to a world map of desertification (United Nations Environment Programme, 1992), shows close correlation between dryland ecosystems and the location of areas that are likely to be threatened by desertification. This correlation is not surprising, however, when the fragile nature of dryland environments is coupled with the impacts of population growth and improper land-use practices on marginal lands. Added to this dire situation is the harshness of the climate itself, which places a persisting stress on both soil and vegetation. As a result, only a relatively little disturbance is necessary to cause ecological instability and imbalance of many and, as a result, lead to environmental degradation and desertification.

Limitations in the sustainable use of natural resources because of severe environmental degradation and desertification are expressed generally by a major breakdown in energy, water, and nutrient cycles; a loss of biological diversity; increases in human stress on the environment associated with increases in both populations and resource consumption per capita.

It is impossible to isolate these limitations from each other (FFolliott et al. , 1995b, Gregersen et al. 2007). Their impacts on the welfare and livelihood of the inhabitants of dryland regions are closely intertwined.

6. Polices and the policy process

Sustaining the use of natural resources in dryland regions and controlling environmental degradation and desertification in these regions are both intrinsically linked to policies and the policy process (Ffolliott et al. , 1995b; Gregersen et al. , 2007). It is important, therefore, that policies related to sustainable use of these resources be identified and thoroughly analyzed initially in the context of established polices. Environmental degradation and desertification are global issues with their resolution through the policy process depending largely on local actions at the land-use level. Solutions, therefore, are often unique to a particular area.

Assessing the effectiveness of established policies, identifying ineffective polices when they occur, and formulating more effective policies when necessary is the general sequence of steps in a process to evaluate the status of current policies. This process is not original and in a sense that is its strength. It is a time tested and accepted process that provides information for the complex and often unpredictable process of policy resolution (Gregersen et al. , 1994). However, the process only works well when the responsible policy-makers, the users and managers of the land and natural resources, and the involved stakeholder groups participate together in the process.

6.1 Assessing the effectiveness of established policies

Policies throughout much the world have been oriented largely toward the delineation and maintenance of large domains of land and natural resources. This orientation is a traditional characteristic of commercial enterprises. Central governments often control far more land than they can manage effectively in many instances. Such an orientation might have been justified in the past. However, it frequently forced the governments to take on the responsibilities of managing large and often unproductive tracts of land or blocks of natural resources through largely restrictive measures and little positive actions.

Many policies focus on optimizing agricultural, livestock, or wood production rather than on the more general purpose of meeting the diverse needs of people. In many cases, policies have included attempts to modify technologies imported from other temperate and moist tropical regions for applications to local conditions. However, land-use strategies and natural resources management practices imported from these other regions were likely developed in countries with relatively settled land use and land tenure policies and where distinctions as to what constitutes livestock grazing, agricultural crop production, and forestry are possible. These distinctions do not necessarily prevail in many of the countries in dryland regions.

Among the key factors to consider in assessing the effectiveness of established policies or alternatively for formulating new policies when it becomes necessary to sustain the use of natural resources while controlling environmental degradation and combating desertification of dryland ecosystems are:

i. Livestock production should be recognized as a de facto component of land and natural resource use. Policies need to reconcile this fact within the overall management of land and natural resources rather than treating it a category to be suppressed or eliminated.
ii. Agricultural crop and livestock production, soil and water conservation measures, obtaining firewood and other wood products, and income generation and local employment should be supported whenever feasible and appropriate.
iii. Wood production need not be the primary objective of forestry-related activities. On the other hand, wood production can be a by-product of forestry-related protection and amenity practices in windbreak plantings, soil stabilization measures, or green belts around urban areas.
iv. Sustainable not short-term practices for the use of land and natural resources should be encouraged in view of the slow rate at which fragile dryland environments respond to improvement interventions.
v. Fairness and equity should be incorporated into policy language to ensure the support of rural populations, which is a necessity for sustaining developmental projects after initial phases of the projects have terminated. This incorporation has not always been the case in the past and, as a consequence, has led to misuse of land and natural resources in many dryland regions.

Existing governmental legislation should also be analyzed for weaknesses and improved on when weaknesses are found (Bromley & Cernea, 1989; Gregersen et al. , 1994; Cortner & Moote 1999). Legislative actions are a means for encouraging the social behavior favorable to land and natural resources policies. For this to happen, however, requires that all people understand and agree to the objectives of land and natural resources legislation. It is also necessary that people perceive provisions of the legislation as equitable and legitimate in relation to their interests, traditions, and moral standards. It is often suggested that the resources of administrative institutions be concentrated on the most relevant and feasible activities that are conducive to applying policies. It might be necessary, therefore, to modify current legislation to reflect the socio-economic conditions and natural resource capacities of a country, keeping in mind regional differences, and the nature and limitations of the administrations that apply them.

6.2 Ineffective policies

Policies are ineffective for a combination of reasons that are easier to explain than to rectify. Policies related to land and natural resources are ineffective when they fail to meet their intended purpose or they are not or cannot be enforced (Gregersen et al. , 1994; Cortner & Moote, 1999). The causes for their ineffectiveness have often been attributed to varying combinations of inadequate knowledge of the proper management practices, low levels of investment, and resources tenure considerations.

6.2.1 Inadequate knowledge of proper management practices

People living in the dryland regions of the world are well-adapted to living in marginal areas. It should not be surprising, therefore, that there is a wealth of indigenous knowledge stored by pastoralists, farmers, traditional healers, and importantly women who are often responsible for the family's survival in periods of environment or socio-economic stress. However, many of these people are impacted by increasing population growth and privatization of common property resources. These dual pressures can force people into shorter-termed practices that are not always sustainable (Cortner & Moote, 1999; Gregersen et al. , 2007). In addition, new comers to a dryland region often bring with them land-use activities from their area of origin that are not necessarily appropriate in dryland environments. Furthermore, improved management practices emerging from research efforts are often beyond the reach of pastoralists and farmers in isolated areas where there is little contact with extension personnel.

Rural people are frequently confronted by technical problems in attempting to implement improved strategies for the use of land and natural resources in the dryland regions of the world because of inadequate knowledge or experience with these practices. Inadequate knowledge of these strategies and management practices generally results from inadequate technical reference, incompetent extensive services, or ineffective communication among technical personnel and the users of the land and natural resources. In turn, it becomes difficult to inform planners, managers, and rural people on the appropriate managerial efforts in dryland ecosystems (Schechter, 1988; Gregersen et al. , 2007). While this problem has been alleviated to some extent by improved educational and training programs for professionals it frequently remains the case for rural people.

6.2.2 Low levels of investment

People living in the dryland regions of the world are often confronted with a vicious cycle of low productivity, low levels of investment, and as a frequent result endemic poverty. Central governments often believe that these people are too marginal to be worth investments. Investments, apart from those made for irrigated agricultural production, have been and remain relatively low (Marples, 1986; Ffolliott et al. , 1995b; Gregersen et al. 2007). Private investments by farmers in rain-fed agriculture are also minimal largely because of the higher risk of erratic rainfall. Lack of investment has exacerbated the gap in agricultural-related productivity of which livestock grazing, forestry-related activities, and other forms of land and natural resources management are often integral components between rain-fed lands and irrigated or wetter rain-fed areas.

The poverty and hunger that are prevalent in sub-Saharan and the Horn of Africa is the most poignant example. However, critical conditions also are found elsewhere (The World Bank, 2005). Improving this situation requires that a variety of technical and institutional problems be solved. Increasing the levels of investment in agricultural, forestry-related activities, and agroforestry interventions is one of the main problems. Its solution includes increased investments in research and extension infrastructures oriented towards building institutional capacity and monitoring the effectiveness of policies and programs. Strategies for risk management need to be developed and programs implemented that lead to equitable distribution of land and income.

6.2.3 Tenure considerations

Systems of tenure are complex in the dryland regions of the world. Codified laws are often underlain with centuries of customary or religious laws that continue to influence rural resource use. For example, Islamic sharia law governs the transfer of title to land and water sources and the access to water and pastures in many dryland areas of Africa, Asia, and in the Middle East even though different and more recent codified laws exist (Raintree, 1987; The World Bank, 2003). There are often separate rules for land, trees, water sources, and traditionally sacred areas. Small watersheds and groves of trees that are conserved carefully and protected by people often constitute the last remaining fragments of indigenous forests and woodlands in many countries and dryland areas including Ghana, Tanzania, Kenya, and Lesotho.

Of particular concern are the relationships between tenure and landless people. A large group of the dryland dwellers are landless refugees who do not have legal access to land or natural resources (Mukhoti, 1986; Fortmann, 1987; Gregersen et al. 2007). As a result, these people cannot participate effectively in developmental projects except when they might be hired temporarily for the planting of trees and shrubs or other short-term tasks. However, sustained involvement in these projects cannot be secured through temporary employment. In country after country, landless people have not received commensurate benefits obtained from developmental projects because of their lack of access to land and natural resources. This access can be provided only through ownership of land or security of land tenure in principle. In reality, granting ownership of lands or natural resources ensuring the security of tenure to landless people is difficult politically if not impossible.

Policies relating to tenure considerations have worked up to a point in some countries. When human population pressures continue to increase, however, many of these policies have to be revised or even abandoned. For example, the demarcation of the "Northern Limit of Cultivation" in the Sahelian Region of West Africa originally set by colonial rulers and later adopted by Sahelian governments had to be abandoned eventually in view of increasing the needs to produce more food (Weber, 1989).

6.3 Formulating more effective policies

It is necessary to encourage the modification of established policies or the formation of new policies in situations where the established policies are ineffective or where inconsistent or conflicting policies have unintended, unanticipated, and negative impacts on one or more groups of people (Gregersen et al. , 1994; Ffolliott et al. , 1995b; Cortner & Moote, 1999). Among the factors that should be considered in formulating more effective policies are:

i. Identifying areas that are at risk of environmental degradations and desertification - A key to the sustaining the use of natural resources is increasing the use of these resources in productive years and then decreasing use in years of environmental stress.
ii. Avoiding the tragedy of the commons - The use of land and natural resources should be allocated to individual or organizational entities for responsibility rather than have open access lands available to everyone.
iii. Avoiding incentives that encourage overutilization of natural resources - For example, incentives to increase agricultural crop production can led to increased soil erosion and, as a result, contributed to environmental degradations and desertification.
iv. Encouraging the development of new and appropriate technologies including indigenous technologies - Mechanisms need to be found for the communication and interchange of this information starting at the local level and progressing to higher levels of management and decision-making.
v. Facilitating local level involvement in formulating more effective policies - The most important factor in this regard is insuring that local people have a level of ownership in the policy process.
vi. Encouraging people to work together to share their collective experiences and indigenous knowledge - People also need to be provided with the knowledge and means for sustaining their use of natural resources and controlling environmental degradation and desertification and, furthermore, government officials must be made aware that piecemeal solutions will not surmount the problem.

Policies that foster more efficient use of natural resources and reduce the threat of continuing environmental degradation and desertification are likely to incorporate one or more of the following policy instruments in their formulation and compliance: regulatory tools, that is, regulations, controls, or permits; fiscal tools such as prices, taxes, and fines; and public investments and management, for example, technical assistance, educational opportunities, research endeavors, or installation of structures and infrastructures.

7. Appropriate strategies for policy implementation

Appropriate strategies for the implementation of responsive policies are necessary to the conservation and sustainable use of natural resources in the dryland regions of the world. Unfortunately, a common set of strategies for implementing land and natural resource policies that have been successful are few in number. While some notable successes have been achieved, most of them took place in other temperate and moist tropical regions as opposed to the dryland regions.

Varying combinations of policies relating to the conservation and sustained use of soil, water, and vegetation have been formulated and implemented on massive scales with positive results obtained in the dryland regions of the world (Armitage, 1985; Gregg, 1988; The World Bank, 1993; Gregersen et al. , 2007). In each case, however, the strategies followed have been different as far as the modes of implementation are concerned. Nevertheless, general strategies for the establishment of energy plantations, water resources management, and other issues related to the sustainable use of natural resources in the dryland regions are suggested below:

i. Political commitments to responsible polices must be strengthened.
ii. Efforts to resettle rural people when necessary and limiting their use of the resources of an area must be preceded by feasibility studies and followed by appropriate compensation.
iii. Efforts in controlling environmental degradation and combating desertification must be based largely on local participation. This participation should be structured on both the immediate and long-term interests of the people who are likely to be united in groups with common economic and social interests.
iv. Establishment of new socio-ecological balances because of the need to resettle rural people should not be pursued in isolation but rather in connection with the security in food, water, and energy production.
v. Small-scale interventions are successful only within a favorable political, economic, and social framework.

Other approaches have been applied elsewhere. For example, trees and shrubs in the dryland regions of the Dominican Republic were nationalized and the wood processing mills were closed in attempting to preserve forest resources. Whatever negative economic and social impacts this action had on people in the Dominican Republic, a striking difference from the barren hills of neighboring Haiti exists (White, 1993; White & Gregersen, 1993). Still other cases are found where massive and in many instances grass-roots conservation of soil and water resources involving the construction of benches or terraces, gully control conservation measures, and building of small dams to control water flows have been encouraged by governments and undertaken by rural people. Examples of these efforts are dispersed in Kenya, Cape Verde, and Tunisia to name only a few countries (Weber, 1989; Hoekstra & Shachak, 1999; Gregersen et al. , 2007). Elsewhere, the emphasis has been placed on planting of trees and shrubs in forests or woodlands or incorporating these planting into on-farm landscapes or land not used for agricultural cropping.

Several countries including Senegal, India, Tanzania, and Botswana have embarked on long-range, nationwide reorientations of their local administrative structures in an attempt to improve efficiencies of their policy and management operations (Bromley & Cernea, 1989). New rural communities have often been created in the process. Local participation in planning and decision-making in relation to land and natural resource use has been incorporated into a more balanced way of collectively deciding which of the resources are to be used under what managerial concepts and by whom. This general approach holds promise in the long-run. As with any effort at redistributions of resources, however, some parts of a population of people end up with less than they had before, and effects of social or economic equity is a matter of who is looking at it.

Strategies for policy implementation vary from one country to another. However, where the efforts are placed in a context that makes sense to the people, the implementing the resultant policies becomes relatively successful. In many instances, however, it has become necessary for governments to shift from only top-down, nationally-focused policies and viewpoints that include motivations or incentives for people in the form of guaranteeing the benefits of their use of the natural resources (Gregersen et al. , 1994; Cortner & Moote, 1999). This approach can be ineffective, though, if not carefully planned and managed.

8. Conclusions

A case can be made that there are gaps in the knowledge necessary for effective policy-making for conservation and the sustainable use of dryland ecosystems. Much of this problem rests with central governments not always knowing or appreciating what makes sense to rural populations and what does not. However, policies, laws, rules, and regulations will all be for naught unless people themselves change their ways of using available land and natural resources. Each country and each area within a country has its own set of interrelationships between people and the land they are living on and natural resources they are dependent on.

Policies are formulated relatively easily but the art is to establish a set of policies that work. While governments often struggle with finding methods to control environmental degradation and combat desertification, rural people are setting fire to plantations of trees that were established to halt degradation and desertification to increase the land available for agriculture. In such cases, governments are often advised to review their land and natural resource policies and the way in which they are carried out. This review also means that it is necessary to understand the attitudes and motivations of those responsible for implementation of a policy once it has been formulated. What is needed for central governments from top to bottom, therefore, is a change in their attitudes and approaches vis-a-vis rural populations of people to attain more effective responses from those who ultimately can make or destroy the best intentioned policy plans.

Policy-makers must understand the marginal and fragile nature of dryland environments and the often marginalized nature of the livelihoods that inhabitants of these environments. The challenge, therefore, is to the reduce risks, improve the productivity, and enhance the quality of life for people while conserving the land and natural resource base. Good policy assessment requires that policy-makers take the time to become familiar with the complex socio-economic and environmental interactions characteristic of dryland ecosystems.

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Part 3

Natural Resources Management and Poverty Alleviation

5

Sustainable Natural Resource Management, a Global Challenge of This Century

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1. Introduction

Food security, environment management and poverty alleviation are main factors contributing the complexity of natural resource management. This chapter intends to show the scope of these challenges in the worldwide and to propose some strategies for managing these challenges or complexities. In definition, food security exists when all people, at all times, have access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life (FAO, 2011a). The world must feed 9.8 billions people by 2050. The challenge of food security is not a new story, but it is still one of the main crises of the world. The food crisis and famine in the Horn of Africa, especially Somalia, has just happened in 2011. Millions of people in Africa and Asia are under threat of famine. This may not be because of only food shortage, but due to lack of capability of some areas to provide food to their people. The President of the International Fund for Agricultural Development (IFAD) in the World Food Day 2011 pointed out that "As long as there is even one person dying of hunger we must do everything within our power to prevent it. The latest crisis in the Horn of Africa shows the terrible human cost of neglect, both of agriculture and rural areas. Droughts are not preventable but famines are" (FAO, 2011b).

Agriculture and natural resources are viewed to be not only the context of food production, but they are the main resources of small-scale rural livelihoods. National resources are viewed as natural capitals of rural households and communities' livelihoods in the framework of Sustainable Rural Livelihood (Fabricius, Koch, Magome, & Rurner, 2004). Despite the importance, the interaction of several factors has limited the capability of agriculture and has threatened natural resources. Urban population and consumers are growing, the pressure on natural resources is increasing and limited public support is available to natural resource management. Factors such as deforestation, land degradation and water scarcity, especially as the result of human activities have adversely affected the productivity of all agricultural and natural ecosystems.

The year 2011 was named as the International Year of Forests by the UN, which stresses the crucial importance of sustainable management of forests worldwide. The FAO (2010) has estimated that approximately 13 million ha forest is lost or converted to other land uses a year. This organization has indicated that deforestation accounts for nearly 20 percent of global greenhouse gas emissions. It also costs the world economy up to five billion dollars every year. According to the the Centre for International Forestry Research (CIFOR), the main causes of deforestation are infrastructure development, agricultural development, and human settlement, for example mining, charcoal production, fire, road building and pasture ranching. These are directly or indirectly related to governments' policies and interventions.

Natural resources degradation may also increase the vulnerability of rural households, which may, in turn, increase their overpressure on natural resources. A sustainable agriculture and Natural Resource Management (NRM) through multi-paradigmatic approaches can be utilized for a better understanding and managing these complexities, which involve and link different paradigms of social actors or their knowledge. This systemic linkage depends on the willingness of these stakeholders.

2. Main challenges

2.1 Poverty and food security

Agriculture and natural resources confront significant challenges in food security and production, environment management and poverty alleviation in this century. According to the UN (2006), the percentage of the developing world's population living in absolute poverty with an income of less than one dollar a day has dropped from 28 percent (1.2 billion) in 1990 to 19 percent (1.07 billion) in 2002 (Fig. 1). This decrease was mostly related to efforts in Asia where this population dropped by nearly a quarter of a billion. However, in Sub-Sahara Africa, 100 million were added to the population living on less than $1 a day between 1990 and 2001 (UNDP, 2005). The poverty analyses also show that another 1.5 billion people live on poverty with $1-$2 a day, which has an increasing trend, estimating to be 1.7 billion people by 2015 (UNDP, 2005). Therefore, 40 percent who lived on less than $2 a day faced the reality or the threat of extreme poverty. According to the World bank (2011), the poverty in South Asia and Sub-Saharan Africa is much worse than any other region of the world (see Fig. 2).

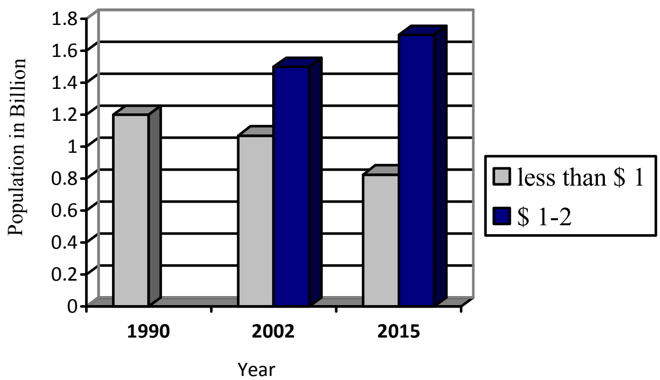
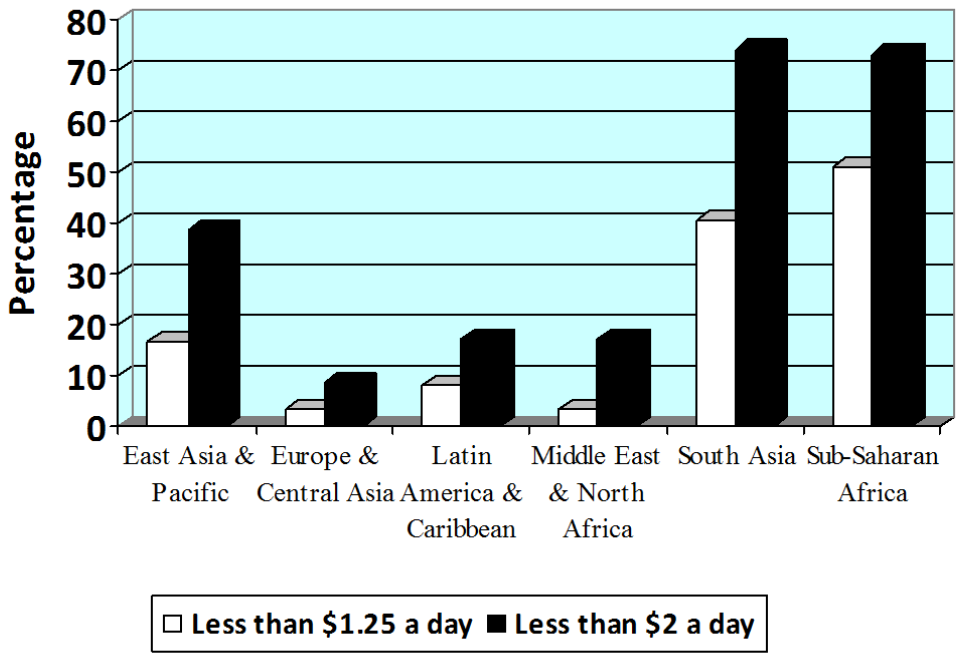


Fig. 1. Population living in less than one USD and 1-2 USD worldwide



Source: Adapted from World Bank (2011).

Fig. 2. Percentage of the world population (except the North America) living in less than $1 and $2

Nearly three quarters of the poor live in rural areas and almost all depend directly or indirectly on agriculture for their livelihoods; therefore, lands, animals, forests, pastures and fish stocks are their main livelihood resources (The World Bank, 2000; UNDP, 2005). Their economic activities are small scale with low productivity of labour and some of them are landless. UNDP (2005) estimates 826 million people will live on $1 a day (14 percent of developing countries' population) and 1.7 billion on $1-$2 a day by 2015, if the current patterns of growth and distribution continue.

Statistics also show that despite the decline of the proportion of the population with chronic hunger, the global total has increased from over 800 million people in 1990 (The World Bank, 2000) to an estimated 824 million (in more than 80 low income developing countries) in 2003 (United Nations, 2006). Malnourished population has also been estimated differently between 2 billion, who suffer from micronutrient deficiency (Hine & Pretty, 2006) to 3.7 billion based on the World Health Organisation's report in 2004 (Pimentel *et al.,* 2006). The occurrence of malnutrition has been due to scarcity or high cost of food or the interfere of political unrests and it causes human suffering and death as well as increasing vulnerability to different diseases (Pimentel *et al.*, 2006).

Whilst overall food production has increased over the last two decades, per capita availability of food, especially cereals has declined. Moreover, the global population is expected to exceed 8.9 billion by 2050 (FAO, 2006a). So more food, water, energy and jobs are needed to maintain life and health at an acceptable level, in which agriculture must be able to double food production by that time.

Increased production by small farmers within food deficit countries could enhance supplies, reduce rural poverty and improve household security. This requires agricultural intensification, combination of technological innovation, improved farming skills and other necessary inputs. However, it is not clear to what extent small farmers can access these requirements.

On the other hand, consideration of environmental sustainability may restrict the ability to increase productivity. Expanding intensification has often had adverse environmental consequences, e.g. deforestation, soil nutrient depletion, falling ground water tables, chemical and waste pollution, expanding deserts, rising CO2 levels, deteriorating grasslands, loss of biodiversity and so forth (Scherr, 1999 ; World Bank & FAO, 2000; Brown, 2005; Dumanski, 2006;).

2.2 Land degradation and soil erosion

The interaction of several factors has limited the capability of agriculture to produce food and has threatened natural resources. Among them, deforestation and land degradation, especially as the result of human activities have globally adversely affected the productivity of all agricultural and natural ecosystems such as croplands, rangelands and forests.

The data available in 1990s shows 14,800 million hectare (13 percent of total cropland area of the world) is affected to some extent by degradation and 84 percent of these degraded land is affected by wind and water soil erosion (Wild, 2003). Loss of soil vegetative cover along with topography, especially in developing countries, is one of the main reasons for soil degradation and is intensified by extensive removal of forests, overgrazing rangelands, cultivation in sloping lands and collecting biomass from ground cover (Wild, 2003; Pimentel, 2006). These activities leave the soil exposed to rain and wind forces to degradation. According to Table 1, about 1.9 billion hectares of land worldwide are affected by human-induced soil degradation (United Nations, 1997; Lal, 2001). This is equal to 15.1% of total land area, though this percentage is different in different regions.

In another global assessment commissioned by the UNEP, it was estimated that 11% of the earth's vegetated land has been moderately or strongly degraded, implying that productivity has been significantly reduced. The extent of degradation is estimated to be particularly high in Africa, where about 3.2 million km^2 are moderately or strongly degraded. In 1998, it was also estimated that about 21 million hectares (210,000 km^2) of cropland became so degraded that crop production becomes uneconomic (Von Baratta, 1998).

According to Pimentel (2006), three quarters of soil erosion worldwide comes from agricultural production where croplands and rangelands have less vegetative cover and a wide area has been converted from forests to croplands. In the early 1990s, about 80 percent of agricultural lands in the world had severe or moderate soil erosion. It has been estimated that croplands producing 30 ton/ha a year have had 75 times the soil erosion experienced by natural ecosystems. In the last four decades, over 30 percent of the world's arable land has become unproductive and an estimate of 10 million ha is abandoned each year. Since humans started farming, about two billion hectare has been abandoned and 1.5 billion hectare, currently under cultivation, is under threat (Pimentel, 2006). Soil erosion has been reported from 13 tons/ha/ year in the US to 40 tons/ha/year in China. These figures have been reported by many scholars and researchers worldwide.

Although water and wind soil erosion is a serious problem worldwide, it is more serious in developing countries of Asia (663×10^6 ha), Africa (413×10^6 ha) and South America (Table 1) where economic and environmental impacts are debatable (Lal, 2001). In these areas, small farmers in marginal and steep lands with poor soil quality are more vulnerable. In US and European countries, soil erosion in croplands is about 10 ton/ha-year, but it is still more than natural state of soil erosion in that 90 percent of US croplands lose their soil faster than normal trend. Soil erosion in rangelands of the US has been 6 ton/ha year, but more than half of the rangelands have had to some extent overgrazing that increase erosion rate in these lands (Pimentel, 2006).

Although rangelands have less soil loss than croplands, there is a high rate of soil erosion in over 50 percent of the world's rangelands, especially in overgrazed lands. Forest areas which have been cleared for crop production or pasture are highly susceptible to soil erosion (Pimentel, 2006). Soil erosion also has on-site and off-site effects on biodiversity loss, water storage capacity decline, intensifying water run-off and carrying vital plant nutrients. Other effects are sedimentation, shortening lifetimes of rivers and reservoirs, overflowing rivers due to deposits, reducing vegetation and soil biota and global warming (Wild, 2003; Morgan, 2005; Pimentel, 2006; Dumanski, 2006). However, more research is needed to develop effective soil and water conservation practices and farmers should be motivated and given enough incentive to implement these projects.

Regions	Total land area (10^6 ha)	Human-induced soil degradation		Soil erosion (10^6 ha)	
		(10^6 ha)	%	Water	Wind
Africa	2966	494	16.7	227	186
Asia	4256	748	17.6	441	222
South America	1768	243	13.7	123	42
Central America	306	63	20.6	46	5
North America	1885	95	5.0	60	35
Europe	950	219	23.1	114	42
Oceania	882	103	11.7	83	16
World	13013	1965	15.1	1094	548

Source: Adapted from Lal (2001)

Table 1. Human-induced soil degradation in different regions of the world in 1991

2.3 Forest degradation

According to FAO (2006b and 2010) global assessment in 2005 and 2010, total forest area was estimated to be almost 4 billion hectares (30 percent of total land). Other wooded land area was 1,376 million ha and other land with tree cover was estimated 76 million ha. This forest area corresponds to 0.62 ha per capita unevenly distributed (62 countries mostly located in arid or semi arid areas had less than 0.1 ha of forest per capita). Despite considerable progress towards conservation and afforestation, trend analysis of forest area still shows a high rate of deforestation between 1990 and 2010. Total deforestation during 1990-2010 was 13 million ha a year, but net global loss of forest was 8.3 million ha a year in 1990-2000, 7.3 million hectare a year in 2000-2005 and 5.2 million hectare per year in 2000-2010). This was due to conversion of forests to agricultural land and lack of enough effort for forest planting, landscape restoration and natural expansion of forests. South America and Africa had a decreasing trend, whereas Europe, North America, Asia and Oceania have had an increasing trend in forest area during 2000-2010.

This assessment also estimated that the total global growing stock for forests was 110 m^3 per hectare in 2005. This showed a slight overall downward tendency since 2000 (except Europe which showed an increase in growing stock). The world's forests store 283 Gigatonnes (Gt) of carbon in their biomass and 638 Gt in their ecosystems including soil, showing they contain more carbon than the entire atmosphere. It was estimated that carbon stocks in forest biomass decreased annually by 1.1 Gt in this period in Africa, Asia and South America, while it increased in other areas.

All these challenges need sustainable strategies in NRM and agricultural and rural development (Pretty, 1998; World Bank & FAO, 2000; McLuskey, 2001). Not only does production face a higher number of demands, but environmental and socio-economic factors raise limits and new concerns that create a complex situation. Some global and national conventions also suggest ways to carry out a sustainable approach for natural resources and land management. Examples are the UN Convention to Combat Desertification, United Nations Framework Convention for Climate Change (UNFCCC), Kyoto Protocol for reducing GHG carbon emission (through soil and forest conservation), international and national water resources conservation and Millennium Development Goals (Dumanski, 2006; FAO, 2006b; United Nations, 2006).

Past efforts on sustainable agriculture and natural resources have been inadequate compared to the scale of deforestation and land degradation. One element of this neglect is related to research and understanding about the threat. According to International Food Policy Research Institute (IFPRI), there is incomplete information on how to meet food needs whilst reducing poverty and protecting the environment (Scherr, 1999). While most ecosystem changes in the recent past have been the result of human activities for food, water, timber, fibre and fuel, more focus has been on scientifically researching the physical or natural aspects of this problem. Socio-economic factors related to sustainable land management have been much less analysed (Dumanski, 2006). Subjects that need more research are impact of investment on land management, institutional and policy barriers, access to markets, knowledge and information dissemination/facilitation, decision making process and support, collective advocacy work, long term financing and other required services.

3. Managing challenges

Managing these challenges depends on a comprehensive understanding of the relevant factors influencing the crisis in natural resources and the capability of agricultural productivity. Many studies are available concerning climatic and physio-topographic factors in NR situation and degradation as well as agricultural productivities, but not much knowledge is available on the relationship of these factors with human activities.

According to FAO (2011b), effective strategies and tools exist that farmers can employ to increase their resilience to climatic and other shocks. "Long-term investment in agriculture -- not only from international donors but from the countries themselves -- is the key to ensuring that such tragedies do not happen again."

All the challenges mentioned in the above sections need sustainable strategies in NRM and agricultural and rural development at global, national and local levels. Despite several global and national conventions, past efforts on sustainable NRM and agriculture in the world have been inadequate compared to the scale of deforestation and land degradation. In a sustainable perspective, it is argued that sustainable growth is possible in currently unimproved and degraded areas or what Chambers and Conway (1991) and Chambers (1997, 2005) refer to as complex, diverse, risk-prone agriculture, while at the same time regenerating natural resources. Pretty (1995 & 1998;) maintains that sustainability itself is a complex and contested concept. Sustainable agriculture is not a simple model or package to be imposed on farmers, especially with the idea of environment or natural resource conservation, but it is more a process for learning to fulfill all its criteria.

Most policies of the development plans in the last decades have focused on the agricultural production increase in order to provide required food for the increasing population. The existing policies and strategies have been mostly either production-oriented or conservation-oriented. This has caused a lack of integration between these two issues as well as limited improvement of small-scale farmers' livelihoods. These programs have mostly been developed using the reductionist or systematic paradigms, which provide few opportunities for the rural communities' active participation (Karamidehkordi, 2007). Production-oriented programs have covered mainly the rich or moderate resource farmers, mostly through a transfer of technology approach. In conservation programs, rural people dependent on natural resources have been considered as main factors responsible for degradation rather than social actors in development who can express their voice and share their knowledge in their management.

The knowledge and capability of rural people to participate in sustainable NRM need to be assessed and improved. It is also essential to know to what extent the supportive knowledge and information systems are effective to facilitate innovation organization. Using systems thinking approaches may help these stakeholders manage these complexities and facilitate sustainable NRM and agriculture to deal with main challenges.

4. Conclusion and recommendations

Sustainable strategies are required in managing the complexities related to utilizing natural resources, agriculture, and rural development at global, national and local levels. The world needs to employ approaches to let people understand these challenges much more comprehensively and holistically than any other time. It is essential to use systems thinking to help us think and learn collectively how to manage these complexities and challenges. We need to employ and facilitate networking and collaborating among social actors mainly, agricultural researchers, natural resource conservationists, rural and nomadic communities, extensionists, agricultural businesses, NGOs, policy makers and markets. Enhancing information exchange networks and establishing multi-actor platforms can facilitate these approaches, which make a link between different studies, paradigms, experiences, worldviews and methodologies. The implication of these multi-paradigm approaches is not only understanding technological and bio-physical realities of an agro-ecosystem such as a watershed, but understanding and managing relationships, interventions, policies, participations, investments and governance methods.

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6

Roles of Diverse Stakeholders in Natural Resources Management and Their Relationships with Regional Bodies in New South Wales, Australia

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Australia

1. Introduction

Governments invest in natural resource management (NRM) because of a lack or failure of markets for ecosystem services and to encourage the adoption of NRM practices that reduce the externalities of resource use (Cary et al., 2002; Beare & Newby, 2005; Stanley et al., 2005). Major global trends in NRM include a greater emphasis on community participation, decentralised activity to the regional scale, a shift from government to governance and a narrowing of the framing of environment policy to a largely utilitarian concept of NRM (Lane et al., 2009). Successive state and national governments in Australia, in actively seeking to improve the condition of Australia's natural resources, established a series of funding arrangements for their protection and enhancement (reviewed by Hajkowicz, 2009; Lockwood et al., 2009). In concert with this funding has been a greater emphasis on accountability for expenditure on public environmental programs because delivery of tangible impacts through recently established regional arrangements has proved difficult to quantify (eg. Australian National Audit Office, 2008).

Cooper et al. (2010) estimated that only 8% of the total land area of the Australian state of NSW is protected in public national parks and reserves. Consequently, the great majority of the NSW land mass and the ecosystem services it provides are subject to impacts from human activity, such as farming, mining, forestry and human settlement, and the capacity of the managers of natural resources to adapt to changed community expectations of sustainability by adopting improved resource management practices.

The work described in this chapter builds on the process described by Brown et al. (2010) to assess natural resource manager capacity, and a series of participatory assessments using that process conducted with agricultural land managers, which is currently being published (Leith et al., in press and Brown et al., in press). We concentrate here on four types of land manager, being: land developers, local government environment officers, coal mine environment officers, and private agricultural land managers. These types represent a range of land managers likely to be found within many catchments in NSW, in other parts of Australia and globally. For the non-agricultural NR managers, focus was drawn on the institutional and organisational values/assets that these types of managers use to influence the condition of natural resources. This was important because, unlike traditional farm businesses, NRM takes place outside of the context of a rural household. The aim of this work was to describe the influence each type of manager has on NRM and their capacity to influence and opportunities to improve NRM. Key results from that work will be used to compare industry and stakeholder perspectives of NRM. This will be followed by a brief discussion of contemporary developments in NRM policy and planning by regional NRM bodies and government that attempt to incorporate the diverse roles NR managers in planning and to circumvent some sources of conflict over resource use.

2. NRM capacity in the context of monitoring, evaluation and reporting

In Australia, activities to monitor and evaluate adaptive capacity for NRM are occurring at national, state, regional and industry scales. The Australian Government's National Land and Water Resources Audit (2002-2008) developed a National NRM Monitoring and Evaluation (M&E) Framework under which a number of projects to develop socioeconomic indicators for natural resource management were conducted. One of those projects focused on adaptive capacity of Australian agricultural land managers.

Nelson et al. (2005) used Australian Bureau of Agricultural and Resource Economics (ABARE) farm survey data to apply the Rural Livelihoods Analysis Framework (Ellis, 2000) to map the adaptive capacity of Australian broad-acre farmers. This enabled a nationally consistent comparison of regions in terms of adaptive capacity, and a preliminary discussion of the primary causes of vulnerability of natural resource managers in the agriculture sector. This analysis was subsequently updated and enhanced by Nelson et al. (2010) to employ a nested approach to weighting of indicators that enabled the ability to 'drill down' through the variables to explore which components of adaptive capacity have the greatest influence in a particular region and which indicators are most prominent.

Adaptive capacity is considered a useful concept because it includes the preconditions necessary to enable adaptation, including social and physical elements, and the ability to mobilise these elements through individual and collective action. Capacity partly depends on the diversity of assets and activities and the flexibility to substitute between them in response to external pressures. This includes the continual process of inventing, adapting and adopting more sustainable farming practices to anticipate and respond to change. Capacity can transcend changes in farm management to include broader livelihood strategies that farm families pursue, for example, through off-farm and non-farm employment.

For NRM purposes, Australia is formally divided into 56 NRM regions each with a community-based board of management with responsibilities for integrated management of the region's natural resources supported by a regional NRM body (Robins & Dovers, 2007). The Australian state of New South Wales (NSW) is divided into 13 NRM regions. The NSW Government implemented a series of 13 state-wide targets to enhance the natural resource condition (biodiversity, land and water resources), and the capacity of regional communities to manage these resources. Regional NRM bodies (called Catchment Management Authorities (CMAs) in NSW) are working with regional natural resource managers to achieve these targets through NRM planning instruments called Catchment Action Plans (CAPs).

Of the State-wide NRM targets, Target 13 deals with the ways in which people influence natural resource (NR) outcomes through their management of natural resources (Figure 1). A joint team from the NSW Office of Environment and Heritage and CSIRO worked with CMAs in NSW to develop ways of identifying, building and reporting the adaptive capacity of NR managers. This team worked with NR interest groups, often established by the CMAs, to enable resource managers to self-assess and communicate their adaptive capacity across each of the catchment areas.

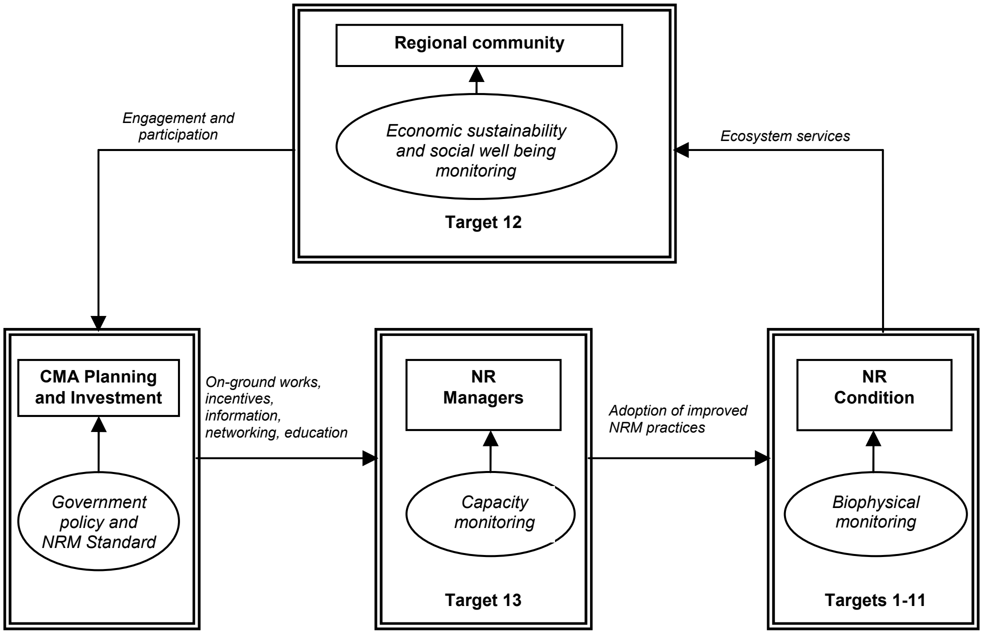

Fig. 1. Conceptual model of the relationship between regional communities, CMAs, natural resource managers and natural resource condition (After Jacobs et al., 2011). Improvements in NRM detected through traditional monitoring of the biophysical aspects of NRM is heavily dependant on improved understanding of the roles of a range of natural resource managers and of monitoring evaluation and reporting of socio-economic indicators of natural resource dependent communities.

Within any single catchment, the practices adopted by managers of land for agriculture often have an overriding impact on the provision of ecosystem services. However, at a local scale other types of NR managers (Figure 2) may have a significant impact on the ability of a CMA to achieve local and regional NRM outcomes associated with Catchment Action Plans. Therefore, the scope of any assessment of capacity needs to be broadened to include non-agricultural NR managers, such as peri-urban landholders and the mining sector, to ensure that regional NRM planning, monitoring and reporting reflects their importance.

Natural Resource Manager Types

Manager type:	**Public NR managers responsible to community.**	**Public company NR managers responsible to shareholders.**	**Private NR managers where business unit is a farm or farm analogue.**
Management of:	• National parks • State forests • Crown reserves • Waters and catchments • Local government parks and reserves	• Mining • Power generation • Plantation forests • Developers	• Agriculture • Aquaculture • Private Native Forests • Boat-based commercial fishing
Assessment frameworks:	**Statutory Reporting Frameworks** Results and Services Plan State of Environment State of Parks	**Global Reporting Initiative** Corporate Social Responsibility Triple Bottom Line	**Rural Livelihoods Analysis** National vulnerability assessment Participatory appraisal techniques
Focus of management:	NR management is primary activity	NR management required as consequence of production	NR management supports production

Fig. 2. A broad spectrum of NR managers may be represented within NSW regions. The most significant regional NR managers should be included in a comprehensive capacity assessment. Examples of reporting frameworks that could be used to inform capacity assessment are shown.

3. Use of participatory monitoring for capacity assessment

We used the rural livelihoods analysis to enable natural resource managers across NSW to assess their adaptive capacity for improved NRM outcomes. The rural livelihoods framework developed by Ellis (2000) views livelihood strategies as comprised of assets or capitals (Box 1) that are continuously invented, accessed and substituted between in the process of generating livelihoods. In the short to medium term, NR managers with a greater diversity of capitals and livelihood options and the ability to switch between them are more likely to be resilient in times of stress. An important strategy for generating sustainable livelihoods in the longer term is the transformation of one form of capital into another. Natural capital, for example, can be transformed into physical and financial capital via economic activity, while financial, social and physical capital can be transformed into human capital by increasing access to education.

Rural livelihoods analysis also recognises that the transformation of capital into livelihoods is mediated by multiple interacting social, institutional and organisational processes. The institutional arrangements that influence the ability of NR managers to substitute between or transform capitals include legislation and regulation, as well as industry and informal community codes of behaviour. These institutional arrangements can affect multiple dimensions of NRM including access rights to resources such as land, water, forests and fisheries. Other institutional arrangements such as vegetation clearing and biodiversity conservation regulations can also affect management and access to markets.

Box 1. The five capitals associated with adaptive capacity

- **Human capital** – the skills, health and education that contribute to the capacity to manage natural resources.
- **Social capital** – the family and community support available, and the networks through which ideas and opportunities are accessed.
- **Natural capital** – the productivity of land, water and biological resources from which rural livelihoods are derived.
- **Physical capital** – the infrastructure, equipment and breeding improvements to crops and livestock that contribute to rural livelihoods.
- **Financial capital** – the level and variability of the different sources of income, savings and credit available to support rural livelihoods.

Non-farm NR managers that contributed significantly to NRM in a region were identified with the assistance of two CMAs that participated in the assessment process (Table 1 provides a rationale for their inclusion). The links between non-farm NR managers (land developers, local government, coal miners) and the regional, agricultural and conservation activities that form the focus of CMA intervention through investment programs remain relatively unexplored.

The aims of the workshop process used to assess capacity were to:

1. define the direct and indirect ways in which farm and non-farm NR managers influence NRM;
2. explore the enabling and constraining factors affecting the capacity of farm and non-farm NR managers to influence improved NRM;
3. identify priorities for collective action among farm and non-farm NR managers, CMAs, government agencies and other stakeholders to improve NRM; and,
4. develop an information base to assist in the *ex ante* evaluation of policy initiatives that alter landholder access to natural resources.

The general approach was to hold workshops of about 3 hours' duration separately with representatives of each of the non-farm NR managers of interest. Participants at each workshop numbered between 6-15 people and were conducted during May 2008. Each workshop involved a general introduction to the MER program and NRM capacity by project staff followed by a facilitated discussion which sought to answer three questions:

1. How do non-farm NR managers influence NRM?
2. What is the capacity of non-farm NR managers to influence improved NRM?
3. What opportunities exist to improve the capacity for NRM of these non-farm NR managers?

The assessment process for private agricultural land managers was to use the workshop format described by Brown et al. (2010). Twelve workshops were conducted between June and December 2008 across NSW in eight catchments with representatives of a range of farmer types (e.g. grazing, cropping, mixed farming). The data from these were reported in Leith et al. (in press) and Brown et al. (in press). In summary, the workshops were designed to allow NR managers to self-assess their capacity for NRM. They identified sets of regionally relevant, contextual indicators of capacity that constrained or enabled practice change and rated the indicators according to the 0–5 scale ("0" effectively constraining NRM, high priority for action; to "5" effectively supporting NRM, low priority for action).

Furthermore, they provided a narrative about the regional importance of these indicators and identified actions that collectively with CMAs and state and federal governments could build aspects of capacity for NRM. For each indicator, they were asked to suggest collective actions that might remove the constraint (or enhance enablement). The aim was to use this list of actions to assist in directing investment of limited funding for NRM into areas where it should be of greatest benefit to NRM outcomes and enable MER on change in regional landholder capacity that results from action to build capacity.

Activity	**Importance and scope of operations**
Land development[1 2] Essential to cope with demographic change.	• NSW had an average annual population growth rate of 1.5% (2006-09) or 318,300 people. • Pressure for land development for housing highest in peri-urban areas that form belts of non-urban land fringing metropolitan centres. • Peri-urban areas, neither fully urban nor rural, form a mosaic of often incompatible and unplanned uses. They usually contain important natural resources, remnant biodiversity and significant landscapes, often remain important for agriculture and recreation, and attract diverse populations of people.
Coal mining[3 4] Coal is the major mineral resource mined in NSW.	• Coal resources located in the 500 km long, 150 km wide Sydney-Gunnedah Basin from the city of Wollongong north to Newcastle and north-westerly through regional NSW into Queensland. • 63 operational coal mines and 30 coal mine development projects (2009-10). • The Port of Hunter is the world's largest exporter of coal and the Hunter region is Australia's largest producer of coal-fired electricity. • 40 open cut mines in the Hunter Valley, covering more than 520 km^2 or approximately 20% of the Valley floor.
Local government[5 6] Democratically elected, third tier of government.	• 152 local councils in NSW. • Range in size, population, structure and in provision of services across urban and rural areas. • Can be made up of a group of urban suburbs, a town or rural areas of up to 10,000 km^2.
Agriculture [2] Provides food, fibre and export income	• Farming businesses in NSW number over 38,000. • Farmers manage over 15 million ha of land or about 81% of the NSW land mass.

Source:
[1] http://www.periurban.org.au/references/monograph4.pdf
[2] http://www.abs.gov.au/AUSSTATS
[3] http://www.dpi.nsw.gov.au/minerals/resources/coal/coalfields
[4] http://www.australiancoalalliance.com/Information/CoalCommunities.pdf
[5] http://www.lgsa.org.au/
[6] http://www.coonambleshire.nsw.gov.au/

Table 1. Significance for NSW of the land manager types that participated in capacity assessment.

The results of the workshops are presented below and reflect the views and opinions of workshop participants at the time of data collection.

4. Workshop results

4.1 Land developers

4.1.1 Influence of land developers on NRM

Urban developers transform land and other natural resource from relatively undeveloped states to more developed states that support human habitation and add to economic development and social wellbeing. This is analogous to transforming relatively undeveloped forms of natural capital into managed forms of natural, physical and financial capitals. This process can have either positive or negative implications for NRM, depending on the pre-existing condition of natural resources and the immediate and ongoing impacts of development.

Developers have important direct and indirect impacts on NRM. Firstly and perhaps most obviously, developers influence NRM directly by driving development processes that transform relatively undeveloped or natural landscapes into more urban landscapes. Urban land development includes decisions on where to locate development across the landscape, and on the nature and intensity of development at specific sites.

Secondly and perhaps less obviously, developers influence the balance of development and conservation across broader regional landscapes. Through land use planning processes they contribute to decisions over which areas are managed for NR outcomes and which areas are conserved or protected. Developers have a strong and increasing awareness of the ecological footprint of development, and their business success is increasingly influenced by their ability to minimise these impacts. Although, not yet operationalised at the time of the workshops, there is growing interest in development offset schemes (such as the NSW Biobanking scheme for biodiversity offsets) with potential to balance development and conservation across the broader landscape. More efficient and intensive development in areas of low natural resource value can create reduced demand to develop areas of high natural value.

4.1.2 Capacity of developers to influence improved NRM

The capacity of developers to influence improved NRM is itself influenced by the policy environment in which land use planning decisions are made. In turn, developers contribute to the creation of institutional arrangements that affect the future management of NR by others.

Developers are influenced by a multitude of legislation and regulations affecting the management of native vegetation, protection of buffer zones along water courses, and the management of vegetation to reduce bushfire hazard among others. The process of development approval currently involves a linear, consecutive resolution of individual issues with separate agencies. No single agency has responsibility for achieving an integrated overall balance of development and NRM outcomes, undermining the perceived credibility of approval processes. The result can be a prescriptive implementation of fragmented regulation which leads to both sub-optimal development and NRM outcomes.

For example, restrictions on development in areas with low conservation value can exacerbate demand for development in areas of higher conservation value.

The institutional context in which developers currently operate does not promote the basic principles of adaptive management and governance. Urban development frequently results in natural areas managed under community title. Developers have a significant influence on establishing the conditions under which these areas are managed into the future. Once established, it is often impractical to seek agreement to adapt management to changing environmental, social or economic conditions across the many joint holders of a community title. The result can be less than ideal NRM outcomes in the longer term.

4.1.3 Opportunities to improve the NRM capacity of developers

Workshop participants identified several opportunities for developers, CMAs, government agencies and other stakeholders to work collectively to improve NRM outcomes:

1. Establish informal deliberative, participatory and adaptive facilitation processes that enable the multiple stakeholders with an interest in urban development to come together to holistically design optimal development and NRM outcomes;
2. Emphasise a whole-of-landscape perspective in planning processes to enable development trade-offs to be made across regional landscapes rather than on a site-by-site basis.
3. Develop holistic land development approval processes that systemically integrate and trade-off the multiple development and NRM outcomes across regional landscapes by:
   - investing in the development of science-based methods and metrics that can inform development/conservation trade off decisions at regional scales; and
   - embed the use of these metrics in deliberative, participatory and adaptive resource governance mechanisms that facilitate the resolution of competing interests between multiple stakeholders to achieve holistically optimal development and natural resource management outcomes

Participants recognised that while CMAs could potentially make an important contribution to improving the capacity of developers to enhance NRM outcomes, urban development is not a CMA’s primary role. CMAs can contribute to the informal facilitation of deliberative, participatory and adaptive processes for resolving competing interests in NRM.

4.2 Local government environment officers

4.2.1 The influence of local government on NRM

In the past, NRM was largely considered to be the responsibility of State governments and was not seen as a core activity of local government. Despite the significant work done by local government on NRM, its role was often not explicitly recognised. The issue of direct and explicit responsibility for NRM is therefore new to many local councils, and as such, it has to compete with other council priorities (e.g. road maintenance, collection of rates and domestic waste disposal). The interests and priorities of elected councillors and their constituents play a significant role in how NRM is prioritised among these competing priorities.

Local councils are, however, involved in a range of activities that affect NRM outcomes:

- Councils endeavour to manage NR appropriately through the management of roadside verges, urban areas, and bushfire related hazards. They face a diverse range of water management issues including: ground water management, water quality, treatment plant upgrades, storm water harvesting, rainwater tanks in urban areas, water sensitive urban design, sediment management, management of septic tanks and issues relating to runoff and pollution, grey-water use and effects on groundwater of, for example, agricultural activities. Councils also manage creeks and riparian zones, including adding habitat complexity to water bodies to allow slow percolation.
- Councils are required to evaluate and approve buildings and construction, and control the use of land through Local Environment Plans (LEP). Local governments influence construction and building in urban areas and focus on the sustainable use of resources (energy consumption, heating, lighting, water etc) through statutory building codes. Furthermore, applications for development require local council approval and there can be reviews of the LEP.
- Local councils have a role to play in NRM related education, and often through an environmental officer who can facilitate on ground NRM activities. These include management of remnant vegetation, weed control, enhancement of biodiversity, minimisation of human impact and riparian vegetation management; and management of pests and weeds (in particular enforcement of control of weeds declared noxious). In addition, councils have some responsibility for management of pest birds in urban areas, and larger vertebrate pests in reserves; a role in community education to raise awareness of salinity problems to minimise its effects in urban areas; and community tree planting (arbour) days.

4.2.2 Capacity of local government to influence improved NRM

The capacity of local governments to improve or influence NRM was considered reasonably high in most local government areas. There were, however, some general and NRM-specific constraints on the ability of local councils to manage natural resources:

- Funding ultimately constrains all local government activities, although there are some issues specific to NRM. For example, the role of local councils in managing NR is not yet recognised fully in the funding allocation formulae used by State governments. Furthermore, there is contention surrounding the idea of raising rates to pay for NRM, and the potential acceptance of this approach by communities varies widely.
- The level of interest and priority given to NRM by communities and within local governments is important for generating activity and achieving outcomes:
  - Councils face a range of competing pressures, and NRM can not be a high priority for all councils at all times. On occasions, community perceptions can unhelpfully transfer most or all of the responsibility to councils rather than accept some level of civic responsibility for NRM.
  - NRM can be in tension with economic development. For example, the scaling back of resource-based industries such as sawmills through the conversion of regional forests to conservation areas and the impacts this may have on local communities can create negative reactions to environmental issues.

    - Some communities show strong interest in NRM, and people often want to contribute. For example, in many regional towns strong community-based environment groups have evolved that are leading NRM activities. A recreational fishing club that removed willows and re-stocked a river with fish by community fund raising and CMA support was proffered as an example of grass-roots support for NRM albeit motivated by largely private-benefit.
    - The interest of local communities and governments need to be aligned to achieve optimal natural resource outcomes. Governments can encourage or discourage local action, and not only through funding but also by assisting in monitoring the NRM outcomes of community activities.
- Issues internal to local government also influence NRM. These issues include the capacity of councils to manage NR, which depends critically on the awareness, knowledge and skills of elected councillors. This in turn influences the priority given to NRM within local government. The difficulty in attracting and retaining qualified staff to small towns and remote rural areas, often for short term contracts, limits the NRM skills-base of local government. Additionally, the success of NRM can depend on alignment between local and state government priorities.

4.2.3 Opportunities to improve the NRM capacity of local government

Participants suggested a range of ways that capacity of local government for NRM could be enhanced. For example, NRM facilitators and community champions have been particularly effective in catalysing community action. They provide a focus for activities, awareness raising and education on how to address NRM challenges, in particular through activities in local schools. They also provide direct support to small communities, coordinate activities, and build the capacity of local communities to manage NR. However, further improvements in capacity are likely to accrue from:

- Appropriate recognition and prioritisation of NRM in council budgets, and in the funding formulae used by State governments to allocate resources to local government.
- Development of a team approach with CMAs and councils in neighbouring local government areas to provide NRM services across a region. This was suggested as a way of sharing resources and coping with skills shortages in NRM.
- Greater co-operation among councils and collaboration with CMAs could assist in funding of NRM facilitators, community champions and environmental officers in line with Council and State government priorities.
- Raising the awareness and knowledge of elected councillors through formal briefings on NRM issues and opportunities to address them could aid their recognition and prioritisation.

4.3 Coal mine environment managers

4.3.1 The influence of mining industry on NRM

The ways that land is used for coal mining, both open cut and underground forms, varies from extraction of resources at one end of the scale to protection and enhancement of NR at the other extreme. There are a range of positive and negative effects on NRM from the process of mining, depending on the potential extent of mineral resources that are targeted for extraction, the extent of buffer areas and the success of regeneration and rehabilitation activities after mining operations are concluded. In general, participants indicated that the aim of the mining industry is to provide mutual positive impacts for NRM at various scales and to involve the local communities where possible in NRM management.

Land is managed by coal mines for three purposes:

1. *Areas of land that are currently subject to mining.* The impacts are both direct on natural resources and indirect on neighbouring landholders from mining activities. To minimise these impacts mining companies generally seek to own the land where these effects occur. In the case of open-cut mining, impacts on neighbouring landholders include air pollution, dust, noise and loss of visual amenity. Where these impacts are significant, neighbouring owners are given an option to sell their land to the mining company. Actions such as the establishment of plans of management with neighbouring landholders are carried out on a site-by-site basis. For underground mining, issues of subsidence are often significant. Companies conduct extensive monitoring to assess the extent of subsidence, and where it occurs, undertake on-ground work towards repairing dams and fences, and installing additional contour banks for erosion control. The mining industry works collaboratively with landholders directly affected by mining to ensure that their current use of land and livelihoods continue. Significant social impacts may also occur as a result of mining operations. For example, land deemed suitable for mining may have been owned by successive generations of farming families and they may have developed strong emotional and cultural ties to the land. In some cases, landholders who sell their properties to mining companies may be offered an option to lease the land back to continue in agriculture after mining operations are completed. After mining has ceased in an area, the industry conducts activities to reclaim and rehabilitate the land. In this case tensions may exist between proponents of biodiversity and the re-establishment of agricultural production on these sites. The industry attempts to manage these tensions through consultation with the community about final landforms and land-uses. This incorporation of community consultation to gauge local values is aspirational rather than regulatory, and the mining industry is not bound by community recommendations on mine site rehabilitation.
2. *Areas earmarked as having potential for mining in the future.* Mining companies may own areas of land containing significant mineral resources that they expect to exploit in the future. This land often remains in use for agriculture either by pastoral companies owned by mining companies or leased to private agricultural operators while awaiting development. For lease-holders of this land, licences are generally for periods of 2 years, but can be for up to 5 years. Such short-term leases often result in limited incentive for good NRM outcomes. While companies do not seek to prescribe management practices, lease-hold agreements often include descriptions of appropriate NRM practices that should be adopted. Examples of management guidelines might include limitations on grazing of river banks and construction of major earth works (dams) without the consent of the mining company and requirements to undertake routine pest and weed control.

3. *Mining area buffer zones.* These are areas on the periphery of mines without potential for mineral extraction but which act as buffer zones for mining activities. In buffer areas, the mining industry encourages the continuation of agricultural production to maintain links to the land, but there is an opportunity to integrate benefits to biodiversity through the use of offsets. This comes from the use of vegetation to screen and reduce the aesthetic impact of mining in adjacent areas of land. In addition to improvements to visual amenity, vegetation plantings may provide some ecosystem services such as cleaner air through dust capture and biodiversity connectivity in the landscape. The mining industry is keen to ensure this land is managed appropriately, with a good balance between production and conservation. Direct partnerships between CMAs and mining companies on buffer zones are common and have resulted in projects that achieve significant NRM outcomes on agricultural land. Such collaborative projects include working with volunteer environmental groups on weed control, tree planting and erosion control, and with neighbouring landholders to revegetate shared riparian areas.

Important outcomes for regional NRM include protection and enhancement of native vegetation, amelioration of soil salinity, contributions to regional biodiversity strategies and NRM monitoring and research activities.

4.3.2 Capacity of mining industry to influence improved NRM

While mining activity is sometimes limited on ecological grounds because of potential impacts on threatened ecosystems, often it presents an opportunity to take marginal pasture land out of production and convert it into conservation land following a period of coal extraction.

Biodiversity offsets schemes, under development at the time of the workshop, afford a methodological approach to reconcile mining with conservation and to help target specific areas with the aim of having a net positive impact on biodiversity outcomes. The mining industry manages offset areas on a case-by-case basis and environmental research on such areas is encouraged. Participants envisioned market-based instruments for carbon sequestration as becoming a feature of offset areas in the future.

In general, participants indicated that mining companies are well aware of NRM issues and their aspirations for raising the profile and importance of NRM in their regions coincides with the activities of CMAs. Although involvement of CMAs in NRM activities on mining land is not mandated formal interaction in the shape of a CMA staff member identified as a designated contact for the industry occurs particularly in catchments were the industry is a significant landholder. The CMA also assists the industry by providing guidance on where in the catchment investment on NRM should occur. This guidance is coupled with appropriate technical experience and often provides financial assistance in the form of incentive payments for landholders. The CMA's Catchment Action Plan is used as a basis for planning and development within the CMA, to align consistency of action, and provides a background for policy statements.

There is now considerable overlap of interest between the mining industry and CMAs, for example in areas affected by salinity and for the management of riparian vegetation. The CMA also has established links to local communities and the mining industry has a strong interest in working with these communities with cooperation from the CMA to form partnerships and set up formal NRM agreements.

4.3.3 Opportunities to improve the NRM capacity of mining industry

The opportunities to improve NRM capacity of the mining industry include:

1. Rationalisation of the number of government agencies with responsibility for aspects of mining operations. There was a perception that there were too many government agencies and for each different management issue there was a range of departments that required liaison.
2. Provision of advice and assistance to the mining industry by CMAs. While CMAs have no role in the regulation of mining activities they can provide a link between regulators and the mining companies. CMAs comment on mining plans, and ensure they are consistent with regional NRM plans to maintain environmental outcomes. The main focus of these activities is in off-mine and buffer areas.
3. Ensure a role for CMAs in the implementation of regional NRM outcomes through involvement in long-term planning for the industry conducted by government mineral resources agencies. This action would facilitate the development of landscape plans across mine sites, improve connections between discrete landholdings, assist in the establishment of biodiversity corridors through offset schemes and raise awareness of the big picture on regional NRM, which often tends to get lost when regulators closely examine single resource management issues.
4. Increase the NRM profile of the industry through improved communication, research and awards for industry environmental excellence.
5. Maintenance of communication and links with local and Indigenous communities. The coal industry, for example, actively gives Indigenous owners a voice in the salvage and management of archaeological sites and influences the management of mining areas to maintain natural and cultural values. The industry needs to maintain good links with Indigenous and non-indigenous local cultural heritage groups. The industry should ensure companies comply with legislation on preservation of cultural heritage.

4.4 Agricultural land managers

4.4.1 The influence of agricultural land managers on NRM

Private agricultural land managers control most of the landmass of Australia and their practices influence the ecosystem services this land provides. Any improvement in the condition of the natural resource base in Australia is heavily dependent on the adoption of more sustainable agricultural practices on private land. While the total number of farms is in decline, the majority are operated by individual families, which support and are supported by the farm business. Therefore, the goals and aspirations of farm families are inextricably linked to agricultural livelihoods. Where improvements to agricultural productivity, farming systems and NR sustainability coincide, the adoption of improved NRM practices is often rapid. For example, adoption of minimum tillage cropping systems, which deliver soil conservation outcomes, is as high as 86% in some parts of Australia (D'Emden & Llewellyn, 2004). It is estimated that Australian farmers spent $3 billion on NRM over 2006-07, managing or preventing weed, pest, land and soil, native vegetation or water-related issues on their properties (Australian Bureau of Statistics, 2008).

Recent shifts in emphasis of government NRM investment away from improvements in agricultural productivity to practices seeking to deliver conservation outcomes may not be compatible with a landholder's goals. The evidence is compelling that up to 75% of farms in some parts of Australia fall below a farm financial benchmark that would provide an acceptable standard of living for a farm family and allow for investment to mitigate income fluctuation and investment for future productivity increases (Barr, 2011). The lack of adoption of conservation practices is often interpreted by government agencies and NRM bodies as a lack of motivation on behalf of landholders for improved NRM. However, such landholders may be unable rather than unwilling to make an in-kind investment in adoption of conservation practices even though they deliver broad public benefits.

4.4.2 Capacity of agricultural land managers to influence improved NRM

Capacity to sustain and improve natural resources at the farm scale depends on a variety of drivers of behaviour, ranging from human characteristics, such as motivation, education, and attitude, to social, cultural, financial and physical considerations which affect people's ability to develop and implement management strategies and actions.

Despite the diverse range of locations, farming systems, demographics and socio-economic contexts of the workshop participants (12 workshops involving approximately 90 landholders throughout NSW), indicators of effective NRM consistently emerged that suggest widespread impediments and drivers of NRM on private land in NSW. In particular, participants emphasised the need for consistent NRM policy at local, state and national scales, inclusive cross-scale institutions, and continued support for successful programs and organisations. Constraints to effective NRM were frequently related to agricultural commodity markets and cultural changes to local communities resulting from underlying national demographic trends.

Leith et al. (in press) showed that the balance between enabling and constraining factors to NRM and their strength (occurrence and importance) varied with the type of livelihood capital. In general, constraints tended to be broad-scale, multi-dimensional issues, such as the trend towards an ageing of the farm population (human capital) and declining farm profitability (financial capital), which are largely beyond the control of individual land managers and do not lend themselves to simple solutions. These complex constraints were often partially offset at a local scale by weaker, frequently ephemeral, enablers of NRM, such as the development of local networks (social capital) and nurseries providing local tree species for revegetation activities (physical capital).

Livelihood assets (capitals) are linked and convertible in various ways. For example, the erosion of financial capital in much of rural Australia because of declining terms of trade has led to falls in employment on farms and out-migration from rural areas. This has left an ageing farm population and a diminished agricultural labour force. The ability to operate a farm with less labour is enabled by increasing physical capital in the form of technologies and large-scale farm machinery. Nevertheless, depleted human capital makes land managers more time-constrained. Participants commonly said that, as they have become busier doing more work with less human and financial resources, they have given a lower priority to social activities, such as attending and organising sporting and social events. Rural towns without such social events, in turn, become less attractive places to live. Not all interaction of the capitals leads to spiralling rural decline. Some workshop groups described how a few well-connected champions had built substantial morale or generated enthusiasm within their community.

Through this generation of human capital, social capital can be enhanced, making communities more attractive. Vibrant communities may be more capable of generating financial and physical resources. Enhancements to natural capital, perhaps through a series of good seasonal conditions, can similarly transform the resources available within a community. Drought, an intrinsic part of the operating environment for landholders in much of Australia, progressively depletes financial, human, social and physical capitals over its duration.

4.4.3 Opportunities to improve the NRM capacity of agricultural land managers

Agricultural land managers view NRM as primarily of secondary importance to commercial farming activities although they recognise that natural resources underpin farm productivity. Actions identified by landholders to address constraints to NRM capacity are best considered in terms of their impact on agricultural livelihoods (Brown et al., in press). Traditionally, direct interaction between government interventions in NRM and agricultural livelihoods occurs through the regulation of landholders' access to natural capital, which changes the way in which landholders combine and transform assets to support agricultural production. Not surprisingly then, of the issues for action identified by landholders to address capacity constraints to effective NRM, many related to changes to transforming structures and processes, such as NRM legislation and policy, price regulation, planning processes and tax incentives. However, equally important were actions that would address the context of rural isolation that contributes to landholders' vulnerability such as social networking, local NRM champions, community input to policy, provision of regional health and counselling services and general community development. Actions that might result in expansion of landholders' portfolio of livelihood assets (capitals) included improvements to the capability and health of soils and to the management of grazing, water and groundcover that contribute to natural capital; skills, knowledge and training that contribute to human capital; and, fencing to enhance land management that contributes to physical capital. NRM action that would expand livelihood strategies focused on diversification of regional employment to provide off-farm income and opportunities for youth; the profitability of agricultural production such as business efficiency and forward contracting; and, the financial contribution of NRM to the farm's ability to support a livelihood, such as through stewardship payments. NRM actions contributing to livelihood outcomes were confined to the commercial and social value of agriculture and the value of agricultural land, one of the constraints to achieving viable farm size.

5. Discussion

The opportunities to enhance the capacity of each of the farm and non-farm NR managers to influence improved NRM outcomes identified during the workshops also suggest obvious opportunities to monitor changes in this capacity over time (Table 2).

A key question in relation to longer term monitoring of capacity is the extent to which the non-farm NR managers consider themselves to be direct managers of natural resources, or as part of the institutional environment influencing the management of natural resources by others. To the extent that non-farm NR managers directly manage natural resources, a conceptual framework analogous to the five capitals on which rural livelihoods analysis is based could provide an appropriate set of indicators for assessing their capacity.

NRM group	Monitoring and evaluation opportunities
Land developers	• Implementation of informal deliberative, participatory and adaptive facilitation processes that enable engagement with multiple stakeholders to holistically design optimal development and NRM outcomes. • Evolution and effectiveness of whole-of-landscape planning processes over time in lieu of existing linear and fragmented approaches. • Development of science-based methods and metrics capable of informing development/conservation trade off decisions across regional landscapes.
Local Government	• Recognition of NRM issues in funding allocation, priority and planning mechanisms of local governments. • Exploitation of opportunities for investment into better NRM outcomes from local government activities and through joint funding applications with other councils and through support of NRM facilitators. • Sharing of resources and expertise of NRM staff across councils and with CMAs. • Raise awareness of the role that local government plays in delivering and supporting natural resource outcomes.
Coal miners	• Improved coordination across government agencies on mining regulation. • Establishment of links with CMAs, regulators and mining companies regarding mining plans, CAPs and native vegetation plans. • Communication with local communities and Indigenous communities to improve awareness of the industry's role in NRM.
Agricultural land managers	• Indicators of resource condition related to broad-scale drivers of agricultural productivity and structural adjustment such as labour force changes, farm profitability, landholders' terms of trade, return on capital, and socio-demographic and cultural changes in the Australian population. • Indicators of the effectiveness of government investment in NRM including the strength of local social networks, locally relevant NRM information, land manager skills, regional research and development capability and engagement of NR managers in planning and decision making.

Table 2. Recommendations for monitoring and evaluation identified for each of the NRM groups.

Each of the non-farm NR managers examined here directly manages NR to some extent as part of their normal operations. However, if the transformation of forms of capital to support diverse livelihood strategies is taken an essential concept underpinning the livelihoods approach, then the distinction between managers of agricultural land and non-farm NR managers becomes clearer. For local government the transformation of capital plays little or no role in its activities and the livelihoods framework would not be a suitable assessment process for monitoring its capacity. The purpose of the mining industry is principally to convert natural capital (minerals) into wealth (financial capital), these activities are conducted by large corporate entities rather than households, and the intervention of mine environment managers in NRM is largely mandated by government. These issues complicate the use of the livelihoods framework for capacity monitoring. Rural livelihoods analysis, however, could be used legitimately to monitor the capacity for NRM of the lease-holders and pastoral companies that manage buffer areas and future sites of mines. The actions of coal mines as effective regulators of NRM on these areas of land could then be viewed through the prism of the rural livelihoods of these managers of agricultural land. While conversion of capital is the central activity of land developers, the institutional framework in which they are embedded and on which they exert significant influence, the relatively short term nature of their involvement in NRM and the lack of dependence of their activities on sustainable NR use (except where mandated by government) again makes the use of a livelihoods approach in capacity monitoring problematical.

Where the influence of non-farm NR managers is largely indirect and mediated through institutional arrangements, such as planning and land use decisions, an alternative framework for monitoring this influence should be used.

5.1 Conflict among stakeholders

While the stakeholders participating in this study expressed similar aspirations toward being more effective managers of natural resources, the nature of their roles (Figure 2) inevitably leads to tension. Close examination of the issues underlying NR conflict is beyond the scope of this chapter. It is nevertheless instructive to recognise the existence of conflict among stakeholders because it leads into a discussion of some contemporary developments in NR policy being trialled in NSW in an attempt to ensure a more holistic approach to the management of land, water and biodiversity by, and for the benefit of, regional communities.

The major sources of conflict in NRM in Australia are well documented and include:

- Demographic change particularly immigration to rural areas close to large population centres (Luck et al., 2011). Conflict arises between NRM stakeholders as a result of changes in land use from predominantly agricultural to multi-functional landscapes and the struggle to maintain ecosystem function and services implied by such changes. Conflict often centres on land use planning to accommodate housing and other developments, escalation of land prices and the divergent social and economic values of new residents from largely urban backgrounds.
- Mineral extraction. Expansion of demand for minerals coupled with the juxtaposition of mining activity and agriculture in areas with high environmental and NR values continues to be a source of conflict in many regions. In particular, externalities from mining activity (NSW Minerals Council, 2011), local social and labour force change (Luck et al., 2011), impacts on agricultural production (Brereton et al., 2008), biodiversity loss (Commonwealth of Australia, 2007) and potential damage to surface and groundwater aquifers (Smith, 2009) are issues of concern to NRM stakeholders. However, the importance of the mining industry as a driver of regional wealth and

provider of services to remote communities (Smith, 2009) ensures that views on mining are not held uniformly by stakeholders or their representatives.

- Sustainable natural resource use. Government attempts to protect broader public benefits often conflict with local exploitation of and dependency on natural resources. In Australia, much of this conflict is centred around water where contemporary 'supply-side' policies have favoured technological and engineering solutions rather than institutional, organisational and community practices for managing water (Godden & Ison, 2010).

These three issues are complex, multi-faceted, contextual in nature and resistant to traditional forms of problem solving making them classic wicked problems (Australian Public Service Commission, 2007).

5.2 A systemic approach to NRM planning

Ison (2010) identified the institutionalization of systems thinking to drive new forms of horizontal governance as required to improve the sustainable use of natural resources. Among the systems approaches to the management of NR, application of the concept of resilience may be a way to resolve the 'wickedness' of NRM problems through improvements to both NR governance and management capacity (Lebel et al., 2006). Resilience is a measure of the amount of change a system can undergo and still retain the same controls on structure and function or remain in the same domain of attraction (Walker & Salt, 2006).

Resilience thinking in the planning of NRM should provide recognition of the systemic interconnection of humans to their environment (Ison & Wallace, 2011). Devolution of NR governance to regional institutions, such as CMAs, is viewed as enhancing the ability to manage catchments as coupled social-ecological systems. In NSW, resilience thinking is being promoted to CMAs as 'a new frame for helping communities understand how their catchments work and where and how they can best intervene to keep landscape systems operating effectively' (Natural Resources Commission [NRC], 2011). CMAs are being encouraged to adopt a resilience approach in upgrading their Catchment Action Plans (CAPs) because it 'influences the types of NRM targets CAPs might contain, the partners that might be involved for the best results, and the type of knowledge that CMAs should draw on to analyse, understand and communicate how the landscape functions' (NRC, 2011).

Many of the issues confounding adoption of a resilience framework for the management of social-ecological systems have been detailed in the literature and include governance (Lebel et al., 2006), surprise (Carpenter et al., 2009), multidisciplinarity (Longstaff, 2009), regional scale (Maru, 2010), community participation and collaboration (Walker et al., 2002, Nkhata et al., 2008), adaptive co-management (Olsson et al., 2004; Rammel et al., 2007), and political and institutional changes not supportive of the resilience paradigm (Leach, 2008). These issues are assumed to be more manageable at regional than at state and national scales because the complexity of the factors affecting ecosystems and the behaviour of actors with influence on the environment is reduced (Lebel et al., 2006).

Olsson et al. (2004) developed a conceptual model for the transformation of a social-ecological system from an undesired trajectory of resource management to a new context for ecosystem management that could help to inform actions at regional scale (Figure 5). This model suggests that to effect a change of trajectory involves building a NRM knowledge base; developing a comprehensive planning and monitoring framework for NR; sustaining inclusive social networks to involve NRM stakeholders and regional communities; and, taking advantage of windows of opportunity for effecting NRM policy changes.

While it is still too early to assess the outcomes of adopting resilience thinking for regional NRM in NSW many of the components of the model are in place. Evidence from the current round of catchment planning being undertaken by CMAs suggests that a formal knowledge base is under construction and CMAs appear to be making good progress towards building capacity to detect and plan to manage thresholds through state-and-transition modelling of regional social-ecological systems (Central West Catchment Management Authority, 2011).

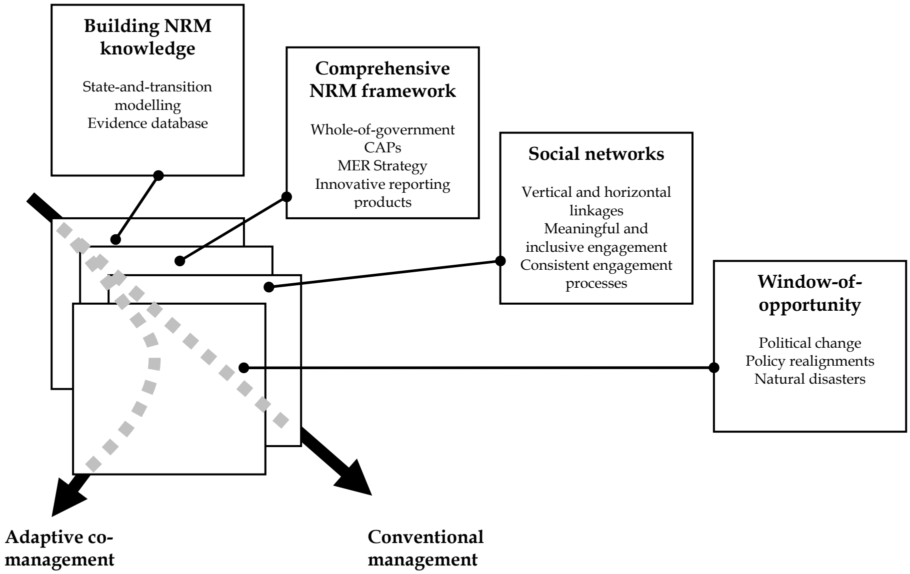

Fig. 5. Conceptual model for the transformation of a social-ecological system from an undesired trajectory of resource management to a new context for ecosystem management (Adapted from Olsson et al., 2004).

A comprehensive framework for defining regional visions and goals for NRM is being established through a whole-of-government approach to catchment planning that includes community engagement processes (NRC, 2011). In addition, a statewide monitoring, evaluation and reporting strategy is in place which seeks to support continuous improvement of NRM and investment decisions (Department of Environment, Climate Change and Water, 2010) through MER of the condition of natural resource assets in the longer term, and of the performance of NRM investment programs in the short and medium term.

Perhaps the component of the model where progress appears most difficult to achieve is in the establishment and maintenance of social networks. At regional scale our work with diverse NRM stakeholders supports that of Olsson et al. (2004) indicating that the capacity to address the range of issues involved with ecosystem management is dispersed over a range of actors at different levels in society from individual landholders through to national policy makers. In particular, CMAs tasked with coordinating regional NRM differ widely in their organizational capacity to meet planning and management responsibilities (Robins & Dovers, 2007). Effective social networks contribute to capacity by providing access to resources embedded in the network and the importance of relationships and partnerships in collaborative community-based projects is well recognised (Lauber et al., 2008).

However, for resilience to become the driver of a transformational shift in the management of social-ecological systems, rather than simply the latest in a string of catchment planning fads, existing institutional frameworks will need to change to accommodate new ways of learning, new ways of sharing information, and new ways of incorporating learning into planning (Allan & Curtis, 2005). Meaningful and inclusive engagement processes that value the context-specific tacit knowledge of NRM stakeholders about the social-ecological system in which they are embedded (Busch, 2004; Smith & Bosch, 2004) are fundamental to this transformation. The knowledge generated through such processes must also be used actively in decision making because policy makers' information about actual institutional performance is very limited, rarely field based, and drawn mainly from interested parties (Fox, 2001). Marshall (2011) suggests that strong incentives need to be created for NRM decision makers to embrace investment decision-making frameworks that are more rigorous and comprehensive than those they currently use. Leith et al. (in press) and Brown et al. (in press) demonstrated that participatory monitoring and evaluation of landholder capacity can provide an appropriate information base for policy-makers on the constraints to changes in the management of NR on private land and may assist in the design of novel strategies to effect change. They argued that the inclusion of an aspirational target for NR manager capacity in a state wide MER strategy, as in the Australian state of New South Wales, was a positive development because it recognised that people are an integral part of the cultivated landscape and that NR managers are key local stakeholders in the delivery of landscape-scale change through their active use and management of NR in maintaining livelihoods (Bohnet, 2009).

In addition, regional NRM bodies and NRM stakeholders need to be prepared to exploit windows of opportunity to promote change in the management of NR that occur through broader political processes or through shocks to national and regional economies, such as those following natural disasters (Bruckner & Ciccone, 2009; Burke & Leigh, 2010). There is evidence in Australia that the opening of such policy windows has recently occurred. At the national scale, and following a severe drought that affected most of Australia, a large-scale planning process is underway to improve the environmental management of the Murray-Darling Basin catchment, the major water catchment of the eastern part of the continent (Connell & Quentin Grafton, 2011). In NSW, a recent change of government has led to increased emphasis in land use planning on food security and local agricultural livelihoods, and a re-evaluation of the impacts of mining, in particular for coal seam gas, on natural resources (NSW Liberals and Nationals, 2011). The extent to which the resolution of these policy processes might involve evolution of governance regimes that assist the transition to a new context for the management of regional ecosystems is at present unclear.

6. Conclusion

Effective NRM requires concerted action on the part of a broad range of actors that influence the management of regional ecosystem services and that extends beyond agricultural landholders. Participatory monitoring of NRM capacity indicates that NRM actors are genuinely interested in contributing to regional NRM planning. However, NRM stakeholders such as the mining industry, land developers and local government need to be engaged by regional NRM bodies and their actions better coordinated with those of agricultural land managers.

The approach described in this chapter is an effective way to define the roles of diverse stakeholders in NRM, to improve their relationships with regional NRM bodies and ensure their perspectives are included in regional NRM plans. Adoption of resilience thinking as a paradigm for systemic NRM planning processes as in the Australian state of NSW, offers hope of transformational change in the management of social-ecological systems.

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7

An Analysis of the Contribution of Community Wildlife Management Areas on Livelihood in Tanzania

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1. Introduction

Community conservation strategies are eminently suited to help meet the Millennium Development Goal (MDGs), especially those related to eradicating poverty and ensuring environmental sustainability (Pathak *et al*. 2005). Indeed, they provide a bridge amongst these goals, which is otherwise weakly developed in most country policies and programmes (Kothari *et al*., 2000). A wide range of motivations can lead to establishment of community conserved areas; these include: Concern for wildlife protection; to secure sustainable access to livelihood resources; to obtain sustainable benefits from ecosystem benefits; to sustain religious, identity or cultural needs, to secure collective or community land tenure, to obtain security from threats, and to obtain financial benefits (*ibid.*). On the other hand, community conserved areas are critical from an ecological and social perspective in many ways e.g. help in conservation of critical ecosystem and threatened species, provide corridors and linkages, offer lessons in integrating customer and statutory laws, help communities in empowering themselves etc (IUCN, 2006).

A close look at various Community Based Conservation (CBC) practices in Africa suggests that while communities are now included in the politics of and policies of conservation, they remain peripheral to defining the ways in which conservation is perceived and nature managed (Kaswamila et al, 2010). That is, although conservation is expanding geographically, devolution and participation remain elusive or passive in nature. In Tanzania, after implementing Community-Based Conservation (CBC) programmes since early 1980s without providing tangible benefits to local communities living adjacent to the protected areas, the government in 2003 adopted a concept of establishing a new category of protected area, the Wildlife Management Areas – areas set aside by village governments to enable local communities to benefit from wildlife resources and at the same time conserve these areas which are crucial as wildlife migratory routes and/or dispersal areas.

This chapter evaluates the impact of the WMA initiative on livelihood and conservation in one of the first five WMAs to attain user rights – consumptive and non-consumptive user rights, the Burunge WMA. Specifically, it seeks to (i) Assess the WMAs financial impacts to local communities (ii) Assess the contribution of the WMA on conservation of wildlife corridors and (iii) assess issues and problems which threaten the sustainability of the WMA

2. The study area

Minjingu, Vilima Vitatu and Mwada villages adjacent to Tarangire National Park in north eastern Tanzania forms part of ten villages forming the Burunge WMA which cover about 280 km^2; officially gazetted on 22nd July 2006. The main ethnic groups in the three villages are the pastoral Maasai and the agro-pastoral Mbugwe. Burunge WMA is of considerable value as it occupies the land and migration corridors between Tarangire National Park, Lake Manyara National Park, and the adjacent Manyara Ranch now known as the Tanzania Lands Conservation Trust (TLCT) under AWF management. The WMA hosts Lake Burunge, an important area for water birds such as greater and lesser flamingo and a range of ducks and shorebirds, and also hosts a large buffalo population that moves in and out of the Tarangire (Madulu *et al*., 2007). The study area is in a semi-arid with average annual precipitation of 750 mm/annum (Kaswamila, 2006). The rainfall pattern is bimodal, with short rains between May and June and long rains between November and January. The months of June through October are normally dry months.

Agriculture and livestock keeping are the main land uses in the study area and is practised by 94% of the population. Other activities include fishing, tourism related businesses (souvenirs, mat weavings) and other small businesses. Crops grown in the area are mainly sorghum, maize, cotton, simsim and groundnuts. Cotton used to be the main cash crop in the past (1970s), but has declined mainly due to its price fall in the world market (BDC, 2004). Other reasons for its decline are untimely payments after crop sale (selling on credit), poor extension services and high costs of agricultural inputs (*ibid*.). The crop production level is low mainly due to climatic limitations (semi-arid) conditions. The village particularly Minjingu and Vilima Vitatu have rich wildlife and tourist attractions such as Lake Burunge and several historical sites: *Nsanga ya Iwe and mwawe wa Nnda, Mawe ya nyani (*rock outcrops used by baboons*), mbuyu wa Tembo* and green stones (BDC, 2004).

3. Community-based conservation in Africa

The most important step needed to help Community Conservation Areas (CCAs) delivers their potential for conservation and livelihood security is difficult: and requires a shift in thought paradigms (Kothari, 2006). Professionals and practioners in the “formal” world of wildlife conservation need to expand their minds to respect the world’s oldest conservationists, indigenous people and local communities (*ibid*). We need to recognise that CCAs are often not just “projects” that communities take up, but are very much a way of life, with grounding in history and tradition, even if many may actually be quite recent (*ibid*). And we also need to convince and lobby governments to provide this respect and recognition (*ibid*). Most of the planet’s biological diversity is located in the tropical countries, primarily on indigenous territories (Kothari *et al*., 2000). Although the indigenous people inhabiting these lands and their traditional rights are being ignored, the fact is that “biodiversity” is well known by them and they have the customs and statutory rights to use and conserve it, as well as to protect their traditional rights.

Policy and legislative changes in a number of eastern and southern African countries together with the dedicated efforts of certain non-governmental organisations and community-based organisations have seen the rise of Community Conservation Areas (CCAs) in the region over the last few decades (Holden *et al*., 2006; Kaswamila, 2006, Kaswamila *et al*., 2007). The devolution of rights to local communities has in a growing number of instances empowered them to manage the land and natural resources, including wildlife furthering regional and global conservation objectives whilst delivering opportunities for sustainable socio-economic development at local level (Holden *et al*., 2006). Impediments to this remain and include a lack of capacity and resources, conservative mindsets within certain conservation and government agencies, political instability, complex community dynamics, and insecure tenure regimes that continue to undermine the rights of local communities (*ibid*). However, as the success stories increase and lessons learned, the benefits that CCAs have to offer are being more broadly realised and accepted by all (*ibid*).

In South Africa for example, in the era of apartheid years, the majority of people were effectively prevented from enjoying the benefits of formal conservation areas, often bearing the costs associated with removal and exclusion from parks (Holden *et al*., 2006). However, with the advent of democracy in 1994, in order to achieve the dual goals of biodiversity conservation and social justice, institutional restructuring was undertaken (particularly at the level of national park agency), and innovative legislative introduced. CCAs in southern Africa have been initiated as a sustainable economic revenue generating opportunity for the community (*ibid*.). Furthermore, they are often key corridors that link state protected areas, increasing the ecological and economic viability of both (*ibid*.).

In Namibia, efforts of a number of far-sighted conservationists and NGOs, with the support of the Ministry of environment and tourism, have resulted in the establishment of a number of successful community conservancies (NASCO, 2004). There are now 44 registered communal area conservancies covering more than 10,500,000 ha (*ibid*). Total income to these conservancies in 2005 was N $ 20.1 million (appr. US $ 3.1 million) (Holden *et al*., 2006). Clear legal rights are given to community institutions, avoiding regional government structures and the need for such structures to further devolve authority. Rather than being defined by artificial units, which potentially force together people who would not normally co-operate, communities define themselves, enabling the development of cohesive social management units with incentives for individuals to cooperate (SASUG, 1997). Communities carry on their normal economic activities within a conservancy, and essentially wildlife and tourism become additional forms of land use (*ibid*.). The conservancy policy and legislation is flexible, with communities able to shape their conservancy according to local social and ecological conditions, and to choose their committees in a manner consistent with their own cultural norms (*Ibid*).

In Botswana, despite the absence of strong rights over wildlife, by 2003, 47 communities comprising 44,000 people had formed trusts for the management of wildlife and natural resources (Arntzen *et al*. 2004). The total income to the trusts was more than BP 7.3 million or about US $1 million (*ibid*.). CCAs in Botswana help to maintain large areas of land under wildlife outside protected areas and according to Arntzen *et al*., (2003) poaching levels are falling in these areas. However, in a number of areas, communities struggle to establish CCAs, because of lack of resources to do the necessary planning, and lack of support from government agencies. In Zimbabwe in 1989 the first two Communal Areas Management

Programme for Indigenous Resources (CAMPFIRE) were granted appropriate authority to manage their wildlife resources and by 2001 this figure had grown to 37 (Holden *et al*., 2006). Of these districts, 14 were wildlife producing districts (other districts focused on their natural resources) involving 94 communities with more than 70,000 communal area households benefiting from wildlife income, which amounted to more than US $ 2 million (Taylor, 2006). The establishment of these CCAs has ensured more effective local management of natural and wildlife resources, whilst providing tangible benefits to communities (*ibid*.). Of 12 primary wildlife districts studied in 1999, three districts had wild land in excess of 90% of the district area, six had 50-70% wild land, and only three had less than 35% (*ibid*.). However, in recent years, habitat available for wildlife is diminishing in some areas because of population pressure and increased demand for agricultural land (*ibid*.).

Unfortunately, the devolution of full rights to the community level has not taken place and the decentralization process has stopped at the level of the district council (Jones, 2003). A significant proportion of wildlife income is retained at a district government level, thereby reducing financial incentive for such activities (*ibid*.). This is reflected in the outcome that the most successful CCAs are those where the district council has devolved authority over wildlife to the local level, providing the control over income and management decision-making (*ibid*.).

4. Methodology

Several methods and techniques were used in the data collection. These included household questionnaire surveys; Knowledge, Attitude and Perception (KAP) analysis; discussion with village, district, and WMA officials; and physical site visits. The details of each aspect are described as follows:

4.1 Selection criteria of the study area

The three villages, viz: Minjingu, Vilima Vitatu, and Mwada were picked based on the several criteria such as coverage of ethnic diversity, richness in wildlife (game), presence of business investors, and potentiality of human-wildlife conflicts.

4.2 Household questionnaire surveys

Face-to-face semi-structured questionnaires comprising open and closed questions were administered to 89 households randomly sampled from the village register books. The sampling exercise was followed by training of field research assistants recruited from each village and pre-testing of the questionnaires. Only members of households aged above 18 years were picked. This age was thought by the author to be appropriate given the nature of the study in that they could provide relevant information regarding the WMA.

4.3 Physical site visits

Site visits were undertaken in WMA villages to assess the implemented socio-economic projects, access to natural resources within the WMA areas, environmental degradation, human encroachment etc. Where necessary, photographs were taken to substantiate the observations made.

4.4 Data analyses

Most of the collected data were of qualitative nature and necessitated use of qualitative data analysis. In addition SPSS software was used in the analysis particularly data from household questionnaires. As for KAP data, the data were completely qualitative in nature and this necessitated the use of qualitative data analysis – intellectual interpretation which was later supported with collected data from WMA stakeholders.

5. Results and discussion

5.1 Socio - economic profile of the respondents

The socio-economic characteristics of the population sample for the surveyed villages are presented in Table 1 below. Males formed more than two-third of the respondents and about 87% of the subjects were between 18 and 54 years of age. As for education, more than 90% had primary school education. This scenario indicates that illiteracy level is high.

Village	**N**	**Gender (%)**		**Age category (%)**			**Education (%)**		
		M	F	18-34	35-54	>54	NF	PR	SS
Minjingu	31	70	30	20	57	23	6	87	7
Vilima Vitatu	29	63	37	31	52	17	7	86	7
Mwada	29	72	28	21	79	0	4	86	10
Total	89	205	95	72	188	40	17	259	24
Average	**29.7**	**68.3**	**31.7**	**24**	**62.7**	**13.3**	**5.7**	**86.3**	**8**

Source: Field data, 2007 N=sample size M=male F=female NF=non-formal PR=primary education SS=secondary education

Table 1. Socio-economic characteristics of the study villages

5.2 Status of WMA economic ventures and its contribution to people's livelihood

In this study several ventures such as tented camps, photographic safaris, hunting enterprises, lodges etc. were identified (See Table 2). What can be deduced from these results is that all investments are owned by investors from outside the villages forming the WMA.

Village	Name of economic venture	Owner (native or non-native)
Mwada	Kibo safari (Oridoy tented lodge), Northern hunting enterprises,	Non-native
Minjingu	Tarangire River camp, Maramboi tented lodge, Paradise campsite, Roika lodge	Non-native
Vilima Vitatu	Kibo photographic safaris, Northern hunting enterprises (Shein), Maramboi tented lodge	Non-native

Table 2. Economic ventures within the WMA

According to field data, between 2007 and 2010, a total of TZS 137,700,704 (US $ 137,700) (See Table 3) were realised from different sources mainly photographic safari, hunting (domestic and tourist), fishing, levy, lodges, and fines. Overall, income over years shows an increasing trend, the highest of about 32% recorded between 2008 and 2009. The increase between 2009 and 201o was 4%. Overall average income increase between 2007 and 2010 was 28%. Considering the overall income realised, the 11 villages forming the WMA (revenue divided equally among villages), the average village population of 3,000 people and average family size of 5 people; individuals and households realised TZS 4,173 (US $ 4.1) and TZS 20, 865 (US $ 20.9) per annum respectively. By all standards this contribution is insignificant if local communities are to use the income as an incentive to conserve.

Source of income (TZS)	2007	2008	2009	2010
Lake Burunge Tented Lodge	0	2,260,000	2,680,000	3,220,000
Maramboi Lodge	0	2,260,000	2,680,000	3,220,000
Uni Afrique Lodge	0	1,080,000	1,670,000	2,080,000
Others (non lodge)	91,374	0	3,600,000	5,400,000
Tourist hunting	13,389,555	13,389,555	14,,500,000	13,389,555
Fishing	315,000	6,000,000	7,600,000	6,000,000
Domestic hunting	0	1,200,000	1,800,000	2,600,000
Land rent	5,00,000	0	0	0
Photographic safari	21,675,665	0	0	0
Fines	0	100,000	200,000	300,000
TOTAL	40, 471,594	26,289,555	34,730,000	36,209,555

Table 3. WMA realized income between 2007 and 2010

A study by Magiri (2011) in Ikoma-Natta (IKONA) WMA, revealed a significant income contribution of the initiative. Between 2007 and 2010, the WMA realized TZS 207,502,407 (US $ 207,500). The five villages forming the WMA each received TZS 41 million (US $ 41,000). Taking into account the average family size of 4 people and the village population of 2,500 people, individuals and households were able to realize TZS 16,400 (US $ 16.4) and 65,600 (US $ 65.6) respectively. This income was four times more than that which was realized by Burunge WMA.

Despite the low income contribution by Burunge WMA, the potential for increased revenue is potentially high. This can be achieved through improving contracts between investors and WMA; capacity building in enterprise management, book keeping, resource inventory and monitoring, village game scout training, and improvement of tourism facilities. Currently the AWF is constructing tourist centre (See Fig. 1).

Fig. 1. Burunge Tourist Centre under costruction. Photo by Gerson Mollel, 2011

5.3 Local people's perception on benefits

Local communities were asked as to whether they are aware of the use of revenues paid to the WMA by investors and its uses in socio-economic development at village level. Results indicate that the funds were mainly used for provision of social services (construction of classrooms, dispensary and village government offices), payment for allowances to WMA staff during meetings and seminars, bursary to students, and in supplementing to village government revenues (See Table 4). On the other hand, different organizations and/or individuals made several indirect contributions. For example, AWF provided a motorbike, 16 pieces of desktop computers, constructed an office and installed electricity in the office. The organization also trained WMA officials, village councilors and VGS on different management aspects. However, due Babati District Council interference on WMA's management a motor-bike and computers were sent to the district headquarters for use by district officials.

Type of project	Investor's name	Take-off year
Construction of 3 classrooms (Nkaiti Secondary School) and desalinization of water – Minjingu village	Roika	2005
Construction of village government house at Vilima Vitatu (Mdori) village	Kibo safaris	2006/07
Capacity building (training of WMA officials, councilors and VGS) – on enterprise management, security and resources management	AWF	2007
Provision of I motorbike and 16 pieces of computers to Vilima Vitatu	USAID	2007
Education sponsorship for 2 students (secondary education)	Northern Hunting	2007

VGS= Village Game Scouts

Table 4. Social development projects initiated by investors within the WMA

Community-based conservation (CBC) benefit sharing schemes in the Tanzania shows mixed results. For example, between 1992 and 2003, Serengeti National Park (SNP) generated US $ 31 million from tourism but only 1.6% was allocated to adjacent villages for socio-economic development projects (Kideghesho & Mokiti, 2003). Instead, a substantial amount was allocated to law enforcement (*ibid.*). Emerton & Mfunda (1999) in their studies in Western Serengeti; found that an individual household got an average of US $ 2.5 per year from benefit sharing received indirectly through implementation of development projects. A study by Kaswamila (2003) in 10 villages adjacent to Kilimanjaro National Park, on the impact of Support for Community Initiated Project (SCIP), revealed that between 1994 and 2001 about US $ 213, 000 was spent on socio-economic development projects in four districts (Moshi Rural, Rombo, Hai & Monduli). However, several weaknesses were observed: 70% of the projects were not priority projects to local communities; there were imbalances in fund allocation; and there was nepotism in disbursement of funds and lack of criteria in allocating funds to villages (*ibid.*). Where decision-making has been devolved to local people, however, for example through eco-tourism, it has been shown to deliver tangible benefits relative to "top-down" projects (e.g. hunting concessions).

In Sinya (Monduli District), located within the Greater Amboseli Ecosystem (Tanzania part), agreement between the village and a local eco-tourism company has led to increase of tourism income generated from bed-night fees. The income increased rapidly during the five years from 1999-2003, from US $ 5,000 to $ 19,000 *(ibid.*). The income has been used for conventional social service infrastructure priorities, notably construction of the primary school dormitory and maintenance of water supply machinery (*ibid.*). Nonetheless, while some revenue has clearly been invested in socially valuable community projects, much of the revenue has not been used well (*ibid.*).

In Engare Sero (Ngorongoro District), the village hosts two campsites belonging to one tour foreign operator and a modest tented lodge belonging to another operator. But unlike in Sinya or Ololosokwan, neither of these developments had a contractual agreement between the tourist company and the village (Nelson, 2004). A company granted title by the village purchased land for the lodge outright, and the land for the two campsites was apparently settled and developed without any local authorization (*ibid.*). The owner of the two campsites pays nothing to the village while the tented camp pays a US $ 5 bed-night fee, considerably less than most villages in the region earn. As a result the village has little stake in income produced by increasing number of tourists (*ibid.*). Estimates of earnings is estimated at US $ 2,500 annually from payments made by lodge, only 5 to10% of that earned through tourism by Sinya or Ololosokwan (*ibid.*).

The preceding discussion has shown that where local people obtain tangible benefits, these act as an incentive to conservation initiatives and vice versa. Also, community-partnership projects are better placed to trickle down benefits to local people. What is important is to devolve power to lower levels (local people). What the people need is to be equipped with enterprise management skills and clear and transparent contractual agreements. In the case of Burunge WMA the possible strategies to achieve a win-win situation could include capacity building to WMA staff (in enterprise management, contract negotiations and wildlife management); transparency in the use of realised funds; share of revenues among villages to consider status of human wildlife conflicts and richness of wildlife; and ensuring that investors are accountable to the WMA council and village leadership and not the district council as it now.

Village	Company	Employees	Male	Female
Minjingu	Maramboi lodge	8	8	0
	Tarangire River Campsite	6	6	0
	Northern hunting	10	10	0
	Paradise campsite	3	2	1
	Kibo safaris	4	4	0
Vilima Vitatu	Kibo safaris	1	1	0
	Northern hunting	3	3	0
	Maramboi lodge	4	4	0
Total		39	38	1

Table 5. Employment status of local communities within the Burunge WMA

5.4 Employment by investment companies

Study results indicate that a total of 39 people were employed (permanent and casual) by seven investment companies as cooks and security guards in Minjingu and Vilima Vitatu (See Table 5). Of these employees, 97% were males with an average monthly wage of TZS. 90,000. Out of the total employees 50% come from villages forming Burunge WMA. The gains from employment in one way or another plays a role in poverty alleviation at household level. In addition, the presence of the WMA has made it possible to recruit some local communities in different ways. For example, the WMA in 2008 recruited an office attendant on permanent basis and is currently paying WMA officials and VGS allowances. VGS allowances are valued at TZS 50,000 (US $ 50) per month.

5.5 General impacts of WMA on livelihood

Local communities were asked to mention both positive and negative impacts of Burunge WMA. Perceived positive included employment, transport assistance to needy people, contribution towards overall village income, conservation, reduced poaching, bursary to students and provision of social services. However, in Minjingu most respondents could not see any positive impact. The non-appreciation of the contribution of WMA in Minjingu could probably be explained by the fact that the village has already submitted her intention to withdrawal from the WMA since 2007.

When asked to mention WMA negative impacts they identified loss of land, poor relationship with WMA staff, resource use restrictions and failure to pay salaries in time. Other negative impacts were increased land use conflicts, trypanosomiasis infection to livestock (Tsetse fly), crop and livestock depredation by wild animals, and deforestation for firewood, charcoal (See Fig. 3), timber for house construction and for medicinal purposes. All these can be described as costs associated with WMA establishment.

Fig. 3. Charcoal furnace within WMA. Photo by Author, 2007

5.6 Constraints associated with establishment of WMA

The identified costs can be categorized into four main groups i.e. human-wildlife conflicts, land-use conflicts, denial of use of forest, non-forest products, environmental degradation and land scarcity. Human-wildlife Conflicts (HWCs) is a significant and growing conservation problem around the world, the direct and indirect costs of wildlife (i.e. damage to crops, livestock, human lives) provide incentives for rural people to kill wildlife and reduce the quantity and quality of wildlife habitats (Nyhus *et al.*, 2005; Thirgood, 2005). Similar situation was observed in the study area. During PRA session youths in Vilima Vitatu HWC identified crop raids, diseases transmission from wildlife to livestock as constraint to local communities and that if not checked antagonism between conservationists and local communities will escalate.

Land-use conflicts was also aired as a cost particularly between nomadic Barabaig and farmers during pasture stress periods (dry season); investors and livestock keepers for grazing land; livestock keepers and farmers over cattle paths-normally in crop land - tense during wet season; and between conservationists (e.g. Tarangire National Park) and local communities over boundaries. Local communities have been complaining for a long time now that Tarangire National Park has taken part of their land particularly the gemstone rich Sarame Mountain. A win-win situation can only be achieved if these conflicts are addressed.

Denial to harvest forest and non-forest products from the WMA was also seen as a cost. The village by-laws prohibit local communities to enter into the conserved area without permission from the village government. This has made local communities unable to freely access forest (poles, timber, charcoal etc.) and non-forest (grass, honey, wildlife etc.) as they used to do before the area attained the WMA status. Denial of local communities to harvest forest products has accelerated deforestation in areas outside the WMA. This is due to the fact that firewood is the only source of domestic energy and the only place to fell trees are those outside the WMA. In addressing the problem of resource access within the WMA, the village governments should set aside special days to allow local communities to harvest dead trees and/or medicinal plants under the supervision of VGS. A long-term solution is to advocate the establishment of community forests in each village or households to have forest lots around their farms which could save the multi-purpose role of provision of firewood/timber and also act as farm boundaries. During the field study deforestation through clearing of land for construction of investors sites (residential, business premises, infrastructure development, and firewood - as source of domestic energy) were evident.

In addition, the establishment of WMA led to loss of agricultural and/or grazing land. However, the losses of land were on unequal proportion. For example, among the eleven villages forming the WMA, Vilima Vitatu, Sangaiwe and Mwada lost 65%, 27% and 19% of their total land respectively. The livelihood implication for this loss is the decline in both cash income and in crop production.

5.7 Importance of WMA relative to other institutions in people's livelihood

In focusing what the WMA means to the local people a Venn diagram as a PRA tool was used to rank various institutions against their role(s) in contributing to people's livelihood.

Results from Vilima Vitatu village which involved three groups of people (youths, adults, elders) indicate that WMA as an institution was lowly ranked relative to other institutions (See Tables). The WMA was rated fourth by elders, 6^{th} by youths and could not be mentioned (had no role) by adults. This suggests that the role of the WMA in improving people's standard of living is still unclear. The institutions with impacts in order of importance were schools, churches and mosques. The possible reasons for ranking high these institutions could be the quality of services provided by these institutions which trickle down to individuals or households.

Elders	Adults	Youths
1. Primary school 2. Dispensary 3. Church/mosque 4. Burunge WMA-two students sponsored in 2007 (form 1 to 6), school construction and teaching aids/equipment 5. NGOs (Land Management Program (savings and credit services); Farm Africa (savings and credits/improved livestock credit); Participatory Agriculture Development Project (PADEP) – agriculture development and savings and credits e.g. Village Cooperative Banks (VICOBA), SACCOS and livestock production/keeping 6. Mweka camp (security and environmental education)	1. Primary school 2. Dispensary 3. Church/mosque 4. Mweka camp	1. Primary school 2. Church/mosque 3. Water sources 4. Dispensary 5. Burunge WMA 6. Mweka camp 7. Hunting block

Source: Field data (2008)

Table 6. Perceived Institutional ranking in Vilima Vitatu

Different reasons were given as to why for example school, dispensary and churches and/or mosques ranked high. This ranking shows how they perceive education as a very important tool in combating poverty indirectly. For the dispensary, it is for its crucial role in saving people's lives while churches and/or mosques are crucial in reducing or avoiding sinful behaviours.

5.8 Suggestions to make WMA effective and sustainable

Local communities and WMA leaders were further probed on mechanisms required to be in place to make Burunge WMA effective and sustainable. The most important suggestions given include improved relationship among investors, local communities and WMA staff, the need to involve local communities in major decisions affecting their livelihood, improvement of business contracts, need for investors to follow village rules and regulation, awareness education and empowerment of local communities in running Burunge WMA (See Table 7).

Suggestions	Minjingu (n=31)	Vilima Vitatu (n=29)	Mwada (n=29)
Follow rules and regulations	40	0	0
Gender discrimination in employment	7	0	0
Improve cooperation	48	14	5
Increase salaries	5	0	0
Involve locals in decision making	0	34	10
Improved contracts	0	38	40
WMA management under village government	0	9	10
Employ youths and locals	0	5	5
Awareness education	0	0	10
Improve VGS allowances	0	0	10
New land use plan	0	0	10

Table 7. Suggestions to make BurungeWMA sustainable

Generic suggestions to enable Burunge WMA to become sustainable include improvement of relationship among WMA main stakeholders at village level, i.e. local communities, investors, and WMA staff; involvement local communities in major issues affecting their day to day life; WMA management to be under village management committees; and slack contract agreements. Furthermore, they suggested that efforts should be made to ensure that income trickle down to household and/or individual level. One local community said: "*I don't have children and therefore I don't benefit from the WMA and therefore I don't have an incentive to conserve*". What can be deduced from this statement is that, it is only when households or individuals benefit that local communities are likely to conserve. Others could be increased employment of local communities by WMA investors particularly for jobs which don't demand high skills. A provision need to be in place in Memorandum of Understandings (MoUs) or contracts specifying this requirement.

As for contract, the investor among others is required to promote the WMA, to ensure that 60% of the employees come from villages forming the WMA, and to provide social services to villages forming the WMA. In addition, EIA is mandatory before take-off of any development project, investor has to address soil and water conservation and/or conserve the areas ecology and payment of deposit a certain amount of money (in dollars) as a collateral depending on the amount of money invested. However, the collateral value is not indicated. Other requirements are: contract duration of three years and termination of contract requires 3 months notice. Most of these requirements have not been fulfilled by the investors. Another technical weakness is on signing of the agreement. The District Game Officer has been signing contracts on behalf of the WMA. It is suggested that signatories should come from the WMA management and should be written in a user-friendly language (Kiswahili) instead of English which requires a certain level of education. About 94% of the populations in the study area have informal and primary school education.

When one of the investor was asked to comment on the contract he had this to say:

"The duration of the contract (of 3 years) is too short as it exposes the investor in risk particularly in a situation where the WMA decides to terminate the contract. Again a three month notice for terminating an agreement is too short".

As a way forward to make the WMA sustainable, the WMA leaders pleaded for the government and other actors to assist in training WMA management in contracts and contract management and for the government to devolve power to the WMA in running their day to day activities. "we could not have lost our computers and a motor-bike had we been free from interference from above" lamented one of the WMA staff who preferred anonymity. The other area requiring immediate attention is paramilitary training to Village Game Scouts (VGS) and availability of patrol gears particularly guns, motor-bikes and/or bicycles. The number of trained VGS is currently nine. This number is very low compared to the WMA coverage of 280 km^2 implying a VGS-Area ratio of 1: 31 km^2 which is extremely very low. Due to lack of reliable transport, they bank on transport provided by Tarangire National Park and/or hired bicycles.

6. Conclusion and recommendations

After almost five years of operation (2006-2011) the WMA has shown a great potential towards improving local peoples livelihood, ecological conservation, and biodiversity conservation in the study area. However, despite the observed successes, the initiative still has numerous challenges such as lack of transparency in revenue uses, slack contracts, non-empowerment of local communities in decision-making, and absence of regulations and implementation strategies to operationalise the new 2009 wildlife Act.

The study recommends:

- The need for having in place WMA regulations and implementation strategy
- Devolving power to local communities to address issues and problems of WMAs
- The need for waging awareness education on the importance of the WMA for both conservation and development
- Initial capital investment to WMAs to assist in resources inventory and in human resources capacity development. This can be done by the District Councils, Tanzania National Parks (TANAPA), Ngorongoro Conservation Area Authority (NCAA), NGOs (local and international) and CBOs
- Strengthening the WMA national umbrella organisation to oversee and promote WMA activities in the country
- Review of the 2002 WMA guidelines to be in line with the new wildlife Act of 2009
- Reduce unnecessary and bureaucratic procedures in establishing WMAs. This can be achieved through streamlining the procedures of establishing WMAs by simplifying the steps (e.g. preparation of land use plans, General management Plans and Strategic Plans). The District Councils should set land use planning among their top budgetary priorities.

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8

Assessment of Livestock Loss Factors in the Western Serengeti, Tanzania

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1. Introduction

Diseases have been documented to be responsible for high loss in livestock production in sub-Saharan Africa (Gifford-Gonzalez, 2000). Historically, diseases have been the factor delaying the introduction of cattle-based economies by as much as one thousand years after the first appearance of small livestock in both eastern and southern Africa (Gifford-Gonzalez, 2000). Diseases that frequently are fatal to livestock production (especially cattle) in sub-Saharan Africa include wildebeest-derived Malignant Catarrhal Fever (MCF), East Coast Fever (ECF), Foot and Mouth Diseases (FMD), worms (helminthes), Rift Valley Fever (RVF), rinderpest, anthrax as well as trypanosomiasis (Kock, 2003; Thomson et al., 2003). Livestock diseases have economical consequences on livestock husbandry at two levels; 1) at the national and local level, the diseases are responsible for direct loss due to mortality or indirectly through lowered production and/or the cost of treatment and prevention (Perry et al., 2002; Kock, 2003). 2) At a global level diseases may affect any opportunity for export of livestock and livestock products between regions or continents, jeopardizing the exchange of products for foreign currency (Kock, 2003; OIE, 2003).

Because of negative attitudes of livestock keepers towards wild carnivores, they often claim wild carnivores being responsible for losses of livestock despite the severe impact of diseases (Mwangi, 1997; Rasmussen, 1999). However, several other factors as theft, drought and poor livestock husbandry may equally cause significant livestock loss (Ogada et al., 2003). The high price received for livestock in livestock auctions, make theft a lucrative business. In Africa theft may increase with the number of animals the household own, because it may be difficult to notice a loss of one or a few animals in a group of several hundred individuals. Moreover, livestock theft may vary with season or between years. During the rainy season, it may be easy to follow the tracks the stolen animal has left behind to the destination. The night with a full moon may not be conducive for livestock raiders because it is possible for livestock keepers to observe that livestock are missing in the night holding enclosure from the household living quarters. In some areas outside Africa, livestock theft has been considered a significant rural crime (WASDA, 2007). Drought may affect livestock directly by reducing the available food and water; hence animals may easily succumb to diseases. Indirectly, drought is normally associated with famine which drives the livestock keepers to trade some individuals to buy food.

The level of livestock depredation may intentionally be exaggerated to attract public attention and/or to mask effects of poor livestock management (Nabane, 1995; Infield, 1996; Nabane, 1996). Such negative attitudes towards carnivores due to perceived levels of predation have been cited as a challenging issue in both wildlife conservation and rural development (Woodroffe, 2000). Conflicts between humans and wild carnivores have been well documented in different parts of the world (Røskaft et al., 2003; Treves & Karanth, 2003; Treves et al., 2004; Røskaft et al., 2007). This conflict has resulted in direct persecution of carnivores to get rid of them close to human settlements (Mills & Hofer, 1998; Woodroffe & Frank, 2005), and resulted in a general dislike of such animals. For example, American citizens do not like wolves *Canis lupus* and coyotes *C. latrans* (Kellert, 1985). Likewise, sheep farmers in Norway show negative attitudes towards large carnivores (Kaltenborn et al., 1998; Vittersø et al., 1998; Kaltenborn et al., 1999; Røskaft et al., 2007). In some parts of Africa, similar negative attitudes towards carnivores have been reported (Lindsey et al., 2005; Kaltenborn et al., 2006; Holmern et al., 2007b). Livestock keepers in Africa have been reported to kill and poison carnivores to reduce the perceived conflict over livestock depredation (Stuart et al., 1985; Berry, 1990; Holekamp & Smale, 1992).

The aim of this study was to assess the factors responsible for livestock loss in households in villages outside the western parts of Serengeti National Park, Tanzania. Specifically the contribution of diseases, theft, depredation and loss in grazing fields due to poor management were assessed.

2. Methods

2.1 Study area

Serengeti National Park (SNP) is situated west of Rift Valley. The western border is close to Lake Victoria while the northern edge borders Kenya (Fig. 1). The central part of SNP was designated as a game reserve in 1929. In 1940 hunting was banned and in 1951 it was declared a national park. The borders have been modified as the park expanded. In 1981 Serengeti was inscribed as a World Heritage Site. The park covers 14 763 km^2 and is the core of the Serengeti ecosystem that includes Ngorongoro Conservation Area, Maswa Game Reserve, Ikorongo-Grumeti Game Reserves and Loliondo Game Controlled Area, in Tanzania as well as the Maasai Mara Natural Reserve in Kenya.

The study was conducted in four villages (Robanda, Nyamakendo, Nattambiso and Kowak) surrounding western Serengeti (Fig. 1). These villages currently suffer from the conflict between conservation priorities of the park and priorities of local communities (Hofer et al., 1996; Loibooki et al., 2002). This is a section of the Serengeti ecosystem that extends westward to Lake Victoria with a relatively high human population density (i.e. 70 people/km^2; growing at a rate of 2.5 % per annum between 1988 and 2002, (URT, 2002). The majority of local communities along the boundaries of western Serengeti are subsistence farmers who keep livestock and practice crop production. Many of the farmers harvest natural resources inside the protected areas for domestic consumption. For instance, during the dry season, livestock keepers illegally graze and water their livestock in the protected areas (Nyahongo et al., 2005). In addition, illegal hunting within the protected areas is well documented and illegal bushmeat hunters may sell the illegally obtained meat to generate income (Arcese et al., 1995; Campbell & Hofer, 1995; Loibooki et al., 2002; Nyahongo et al., 2005; Holmern et al., 2007a).

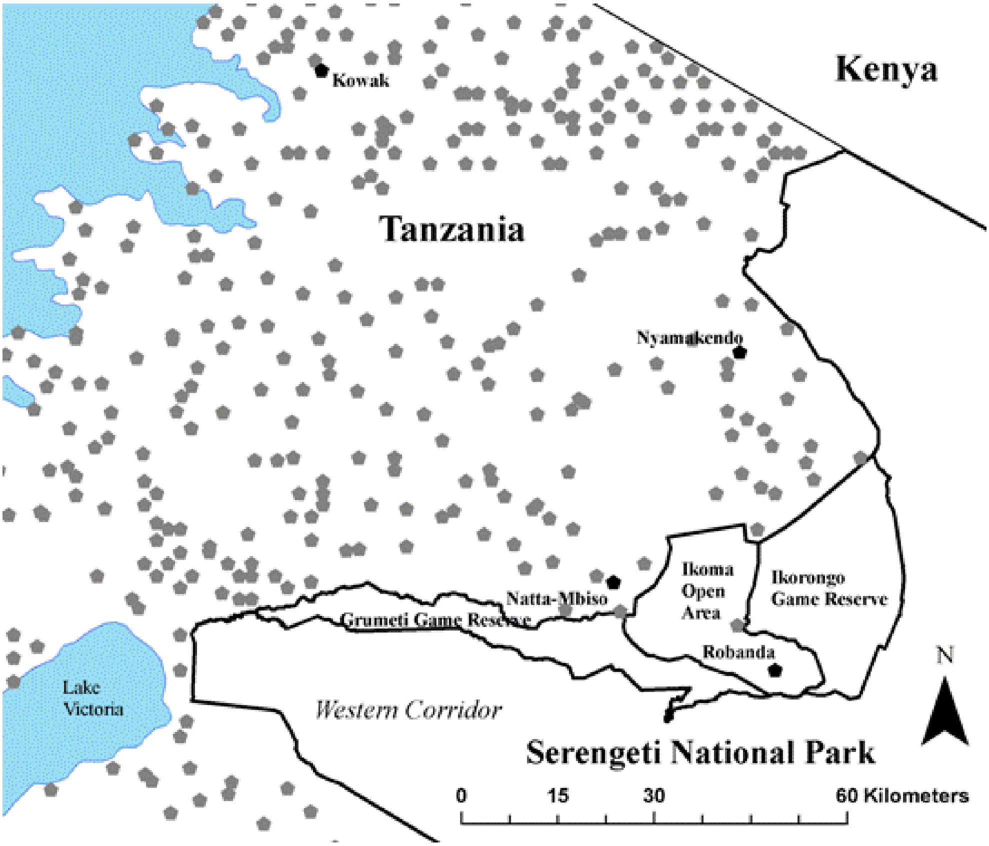


Fig. 1. Map of the western Serengeti showing the sampled villages.

3. Data collection

The current study was conducted between April and December 2006. Households were selected in the following four villages; Robanda, Nyamakendo, Nattambiso and Kowak. The first three villages were within 10 km from the boundary of the park while Kowak village was located about 80 km from the park. Households were selected randomly according to household lists in the villages. For practical reasons (livestock counting time), we omitted household with more than 200 individual cattle, goats or sheep because it was difficult to count the animals each time. January, February and March 2006 were spent in the villages to introduce researchers to livestock keepers and to establish baseline data on livestock numbers per selected household. Livestock owners were informed about the essence of this study and were assured that the data was only collected for research purpose and not for other purposes like baseline data for setting livestock levels by the government. After recording the baseline data (i.e. initial numbers of livestock per selected household), we appointed enumerators. Enumerators were recording any livestock that died due to diseases, were lost while grazing in the field (hereafter referred to as poor management), those which were stolen or were depredated. In addition they recorded livestock that were slaughtered. The gain of livestock recorded included new-born calves, bought or paid as dowry. While enumerators were collecting data on a daily basis, the researchers visited each household after every three months to recount the animals in order to cross check the data that enumerators collected. This was due to the fact that a researcher was also doing some questionnaire surveys in the area. Furthermore, livestock owners were asked about the livestock status during the past three months. Livestock were either counted in the morning before being sent out for grazing (normally 2 to 3 km away from the night holding enclosures) or in the evening when they were brought back to the night holding enclosures. The counting rate was 15 to 20 households per day and we spent one week in each village.

All livestock were prized according to matured livestock because market prices for livestock are only set for mature animals. This allowed us to be able to calculate the mean cost of livestock loss causes per household per year.

4. Statistical analyses

All analyses were performed using SPSS 16 statistical package. Non-parametric statistics were applied to test differences among the loss factors.

5. Results

5.1 Causes of livestock gain and loss

Mean household livestock and the subsequent costs or benefits in monetary terms for the current values of livestock species in each village are summarized in Tables 1 and 2.

Regardless of household locality, various loss causes affected livestock differently (cattle: Friedman test, $\chi^2 = 233.7$, df = 3, n = 182, $p < 0.001$; goats: Friedman test, $\chi^2 = 134.1$ df = 3, n = 155, $p < 0.001$; sheep: Friedman test, $\chi^2 = 81.3$, df = 3, n = 123, $p < 0.001$, Fig. 2). Furthermore, mean number of cattle and goats sold per household was higher than the number slaughtered (cattle: Wilcoxon sign rank test, Z = -7.24, n = 182, $p < 0.001$; goats: Wilcoxon sign rank test, Z = -3.214, n = 155, p = 0.001) but this was not the case for sheep (Wilcoxon sign rank test, Z = -0.70, n = 123, p = 0.484). In all households, new born calves, and not animals that were bought or paid as dowry, was the significant source of replenishment of livestock numbers (cattle: Wilcoxon sign rank test, Z = -8.54, n = 182, $p < 0.001$; goats: Wilcoxon sign rank test, Z = -8.38, n = 155, $p < 0.001$; Sheep: Wilcoxon sign rank test, Z = -7.56, n = 123, $p < 0.001$).

Livestock numbers and loss/gain	Robanda			Nyamakendo			Nattambiso			Kowak			Overall		
	Cattle	Goats	Sheep	Cattle	Goats	Sheep	Cattle	Goats	Sheep	Cattle	Goats	Sheep	Cattle	Goats	Sheep
N	37	10	15	49	49	26	46	45	28	50	51	54			
Mean numbers (± SD)	23.4 (17.2)	9.4 (6.0)	13.0 (22.9)	15.2 (12.9)	13.9 (12.2)	8.3 (14.0)	21.6 (12.2)	16.8 (15.0)	14.6 (14.7)	22.5 (22.1)	8.5 (11.7)	9.0 (11.8)	20.5 (16.8)	12.1 (11.2)	11.2 (15.8)
Livestock gain (%)															
Newborn	10.3	21.3	16.2	5.9	15.1	10.8	9.3	16.1	18.5	5.3	11.8	11.1	7.7	16.1	14.2
Bought	1.7	1.1	0.8	3.3	3.6	1.2	2.3	2.4	2.0	0.9	2.3	2.2	2.1	2.4	1.6
Livestock loss (%)															
Diseases	3.4	4.3	5.4	2.6	6.5	2.4	5.1	10.1	5.5	3.1	7.1	6.7	3.5	7.0	5.0
Loss in the bush	0.4	0	1.5	0.2	1.4	0	0.5	1.2	1.4	0.4	1.2	1.1	0.4	0.9	1.0
Depredation	0.4	0.3	1.5	0.1	0.7	1.2	0.1	1.8	0.7	0.3	4.7	5.6	0.2	1.9	2.2
Theft	0	0	0.1	0.2	0.1	1.2	0.1	0.1	0.1	0.2	0.3	0.3	0.1	0.1	0.4
Household expenditure (%)															
Sold	2.1	3.2	4.6	4.6	5.8	2.4	2.8	2.4	1.4	1.3	3.5	4.4	2.7	3.7	3.2
Slaughtered	0.4	1.1	0.8	0.5	1.4	1.2	0.5	3.0	2.0	0.1	2.3	2.2	0.4	2.0	1.6
Mean recruitment (%)	5.3	13.5	3.1	1.0	2.8	3.6	2.5	-0.1	9.4	0.8	-5.0	-7.0	2.4	2.8	2.3

Note: % means the percentage of the total livestock per village.

Table 1. Mean number of livestock per household and proportion of livestock loss or gain causes (livestock loss causes: diseases, loss in the bush (poor management while grazing), depredation and theft; livestock gain: newborn and bought/paid as dowry; household expenditure: sold and slaughtered for meat)

5.2 Comparison of livestock loss causes among villages

Overall, the mean numbers of livestock that were depredated was higher in Kowak village (about 80 km from the park boundary) than in villages that were close to the park boundary (Nattambiso, Nyamakendo and Robanda) (Kruskal-Wallis, $H = 14.52$, $df = 3$, $p = 0.002$, Kowak: rank = 252, n = 156, Nattambiso: rank = 223.6, n = 119, Nyamakendo: rank = 211.7, n = 123, Robanda: rank = 225.8, n = 62). However, the difference among species that were depredated among villages was not statistically significant (Cattle: $p = 0.09$, Goat: $p = 0.113$, Sheep: $p = 0.119$). In all livestock depredation events spotted hyena *Crocuta crocuta* was the only carnivore reported to be responsible for livestock killing.

Mean number of cattle that died of diseases differed significantly among the villages (Kruskal-Wallis, $H = 17.07$, $df = 3$, $p = 0.001$). Furthermore, the difference in mean number of cattle that were stolen among villages was almost significant (Kruskal-Wallis, $H = 7.12$, $df = 3$, $p = 0.068$). The remaining cattle loss causes did not differ significantly among villages ($p > 0.09$ for all cases).

Loss causes in goats did not differ significantly among the four villages ($p > 0.076$ for all cases). However, for sheep, loss due to diseases and poor management differed significantly among the villages (Kruskal-Wallis, $H = 9.10$, $df = 3$, $p = 0.028$ and $H = 8.85$, $df = 3$, $p = 0.031$, respectively), while theft and depredation on livestock did not differ among the four villages (p > 0.118 for all cases).

5.3 Comparison of livestock loss causes among livestock species

Generally, regardless of distance from the park boundary, mean number of livestock species that were sold, slaughtered for food and that were killed by spotted hyenas differed significantly between livestock species (sold: Kruskal-Wallis, H = 10.82, df = 2, p = 0.005; slaughtered: Kruskal-Wallis, H = 17.09, df = 2, p < 0.001; predated: Kruskal-Wallis, H = 14.01, df = 2, p = 0.001). Households sold more cattle (mean rank = 248.5) than goats (mean rank = 231.4) or sheep (mean rank = 202.7). However, households slaughtered more goats for food (mean rank = 249.6) than sheep (mean rank = 243.2) or cattle (mean rank = 205.6). In contrast, sheep were more frequently killed by spotted hyenas (mean rank = 246.6) than goats or cattle (goat: mean rank = 241.1; cattle: mean rank = 210.6). The remaining loss causes did not differ significantly among species (p > 0.151).

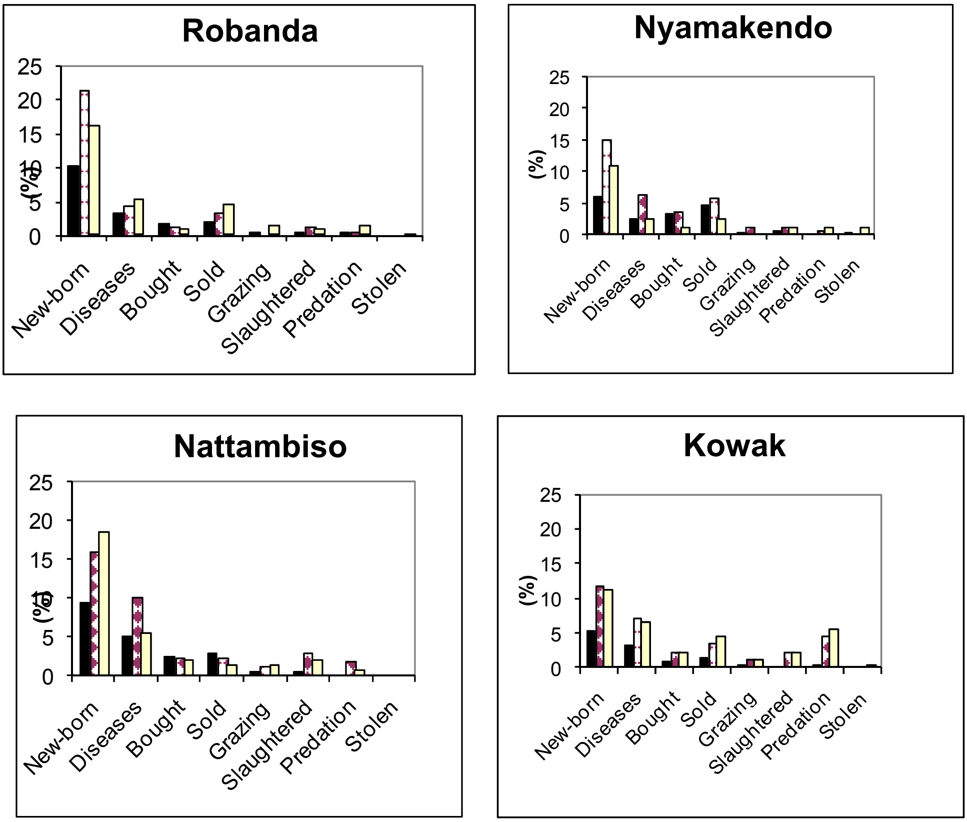
Livestock numbers and loss/gain	Robanda			Nyamakendo			Nattambiso			Kowak			Overall values (US$)		
	Cattle	Goats	Sheep	Cattle	Goats	Sheep	Cattle	Goats	Sheep	Cattle	Goats	Sheep	Cattle	Goats	Sheep
Mean value of livestock	1872.0	188.0	260.0	1216.0	278.0	166.0	1728.0	336.0	292.0	1800.0	170.0	180.0	1654.0	243.0	224.0
Livestock gain values (US$)															
Newborn	192.8	40.0	42.1	71.7	42.0	17.9	160.7	54.1	54.0	95.4	20.1	20.0	130.1	39.1	33.5
Bought	31.8	2.1	2.1	40.1	10.0	2.0	39.7	33.9	5.8	16.2	3.9	4.0	31.9	12.5	3.5
Livestock loss (US$)															
Disease	63.6	8.1	14.0	31.6	18.1	4.0	88.1	10.1	16.1	55.8	12.1	12.1	59.8	12.1	11.6
Depredation	7.5	0.6	3.9	1.2	1.9	2.0	1.7	6.0	2.0	5.4	8.0	10.1	4.0	4.1	4.5
Loss in the bush	7.5	0	3.9	2.4	3.9	0	8.6	4.0	4.1	7.2	2.0	2.0	6.4	2.5	2.5
Theft	0	0	0.3	2.4	0.3	2.0	1.7	0.3	0.3	3.6	0.5	0.5	1.9	0.3	0.8
Household expenditure (US$)															
Sold	39.3	6.0	12.0	55.9	16.1	4.0	48.4	8.1	4.1	23.4	5.9	7.9	41.8	9.0	7.0
Slaughtered	7.5	6.0	2.1	6.1	3.9	2.0	8.6	10.1	5.8	1.8	3.9	4.0	6.0	6.0	4.5

Note: Mean local market price of one cattle in the study area was US$ 80, and for goat/sheep was US$ 20 in 2006, (the prices were for mature animals).

Table 2. Cost and benefit implications of livestock loss and/or gain causes (US $)

5.4 Economic significance of livestock loss or gain causes

In total, the mean economic value of livestock that households from four villages owned was TSh 3,181,500 (US$ 2121) (sum of cattle, goats and sheep per household) and newborn calves per household were worth TSh 304,050 (US$ 202.7). When the effect of livestock loss causes were pooled, diseases were responsible for TSh 124,500 (US$ 83) per household, while wild carnivores caused TSh 18,900 (US$ 12.6) per household. On average, the value of livestock sold per household was TSh 86,700 (US$ 57.8). Livestock losses due to theft and poor management were TSh 21,600 (US$ 14.4) while animals slaughtered for meat were worth TSh 24,750 (US$ 16.5) per household. Each village cost-benefit analysis of each loss or gain causes is summarized in Table 2.



Loss/gain factors Loss/gain factors

Note: Solid black column represent cattle; column with dotted represent goat and open column represent sheep

Fig. 2. Overall livestock population dynamics (loss and gain) in four villages recorded from April to December 2006.

6. Discussion

The results of this study suggest that diseases are responsible for higher livestock loss than any other cause within and among villages. However, sheep loss due to diseases and poor management differed significantly among the villages. Mean number of cattle and goats sold was higher than the number slaughtered in all villages. In all households, new born calves were the most significant source of replenishment of livestock numbers. Livestock species that were sold, slaughtered for food and killed by spotted hyenas differed significantly between species whereof goats and sheep were more frequently slaughtered for food than cattle.

Disease is the major factor responsible for livestock loss in sub-Saharan Africa (Gifford-Gonzalez, 2000). This factor alone, although not recognized by farmers in Africa (Mwangi, 1997), was responsible for a loss of US$ 83.5 per household during the nine months study period. When this figure is compared to the average annual cash income per household in the western Serengeti (US$ 140, (Borge, 2003), loss because of diseases were responsible for 59.6 % of the average annual household income in the target villages. On average, diseases contributed 5.1 times more of livestock loss than depredation. This observation is consistent with previous studies in the same area when farmers were requested to rank major factors of livestock loss (Nyahongo, 2004). Livestock keepers may not observe the direct effect of diseases on their livestock production due to the fact that sick animals may be slaughtered and used as food or sold to neighbors while carnivores often consume all edible parts of a kill, leaving nothing for human consumption. Moreover, diseases often kill a larger number of new born calves than adults (Nyahongo, pers. Obs, 2006). Livestock keepers may not observe this as an important loss because the capital investment in terms of veterinary services, feeding or grazing time and/or output in terms of meat or money (when sold) is relatively much lower for new-born calves than for adults. Moreover, due to poor livestock management records, livestock keepers may not be able to know how many livestock they loose to diseases within a specific period of time. Most of the household in this study did not keep any record showing their number of livestock, new born or even the last time animals were treated and the costs implication. In contrast, when a predator breaks into the livestock enclosures, usually at night (Nyahongo, 2004; Kolowski & Holekamp, 2006; Holmern et al., 2007b) it may kill several adult animals which may result in serious economic consequences for the livestock keepers. However, since the compensation scheme that may offset some of the costs are always lacking in Tanzania, negative attitudes towards carnivores may have developed among farmers, which have resulted in retaliatory killing practices of carnivores in or close to village proximities (Holekamp & Smale, 1992; Ogada et al., 2003; Dickman, 2005; Frank et al., 2005; Graham et al., 2005; Holmern et al., 2007b).

A relatively higher number of sheep and goats were depredated by spotted hyena in the village that was located furthest away from the park boundary. This suggests that even in open areas with high anthropogenic activities, there are still some refuges for some large carnivores like spotted hyenas. This observation suggests a need of including a section in the current wildlife policy to accommodate the protection of wildlife in anthropogenic dominated areas. For instance, certain carnivore species such as spotted hyenas have the ability to commute up to 80 km (Hofer & East, 1993) allowing them to forage even in villages located far from the protected areas. The findings of the present study is inconsistent with the idea that high depredation is always highest close to reserves boundaries (Mwangi, 1997). However, as Woodroffe (2000) puts it, behavioral plasticity of certain carnivore species facilitate their adaptive adjustment to an increasingly precarious lifestyle in proximity to human, a fact that was reported for spotted hyenas in the Maasai Mara ecosystem (Boydston et al., 2003). Thus, we cannot conclude that the spotted hyenas reported at the distant villages commuted from Serengeti or were resident to the village areas.

Analyses of our data suggests that cattle are kept to solve household needs that require relatively huge amounts of money while goats and sheep are kept to tackle small household needs and/or are slaughtered to provide meat protein to the household. This might be due to the fact that the economic value of one cattle is equivalent to about four goats or sheep. These ideas are supported by comparing the number of cattle, goats and sheep that were slaughtered and those that were sold. The proportions of cattle slaughtered were far less than those sold by households in the study villages (Table 1, Fig 2).

Variables like available water and grazing land, weather, market prices of meat (that could lead to elevated theft rate), and animal population dynamics in the villages and in the protected areas adjacent to village areas, diseases occurrence, may, as the variables included in the analyses, show considerable between year variations. These confounding variables, which cannot be controlled for in a snap shot study like the present one, might have influenced the data we collected. For instance, death of livestock due to diseases may increase with drought or with rain intensity and duration, which cannot be precisely compared within a year because intensity of rain and duration of rain seasons may differ in different areas each year in Tanzania affecting pasture quality and available water for animals. Drought may also influence the number of livestock sold to buy food, because crop production in the country largely depends on rain. Weather, on the other hand may influence the survival of new born calves or may influence the level of depredation. Woodroffe and Frank (2005) observed that rate of livestock depredation by large carnivores increased with increasing rainfall. Exclusion of households with more than 200 animals might have further led to an underestimation of livestock loss because more death from disease (due to density dependent danger of infectious diseases), livestock depredation, theft and loss due to poor management in the grazing field may be expected to increase with an increase in livestock numbers.

7. Conclusion

The results from this study show that diseases are the major cause of livestock loss in villages surrounding SNP and that the levels of loss do not vary much among households in the western Serengeti. In contrast, livestock depredation by spotted hyena was relatively low, although it was relatively higher for goats and sheep in household at the most distant village. Likewise, poor management and theft that can be managed at household level causes livestock losses as well. However, at the household level, a single depredation event may cause a serious economic loss.

Livestock depredation may be higher in the areas with high human activities, which encourage wildlife managers, conservationists and wildlife ecologists to think deeply about livestock depredation along the gradient of distance from the park and the future conservation of the carnivores along the same gradient.

This study suggest that local people would benefit from better education on animal husbandry practices and extension service to help them maintain the health of their livestock and to prevent theft and loss of livestock while grazing. We recommend that disease control and management should be integrated as part of the regional and national development programs to limit disease transmission between livestock and wildlife and even among livestock in the villages. Further studies on the types and epidemiology of diseases causing major livestock losses in the area should be conducted in order to design appropriate disease control measures.

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