Annals of Arid Zone 41(3&4): 217-232, 2002

Watershed Management: A Rational Approach to Producing, Conserving, and Sustaining Natural Resources

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Abstract: A watershed management approach to land stewardship accommodates the interests of the widest possible number of people. The approach examines the benefits obtained from land stewardship by optimizing production and maintaining environmental integrity. It also facilitates more effective conflict resolution from a sustainability perspective. The approach further recognizes that future generations of people deserve to inherit landscapes that are capable of producing the needed goods and services while maintaining ecosystem health and economic stability. How watershed management is implemented to conserve and sustain the flow of high quality water, wood production and other forestry activities, livestock production, and agricultural cropping and to mitigate effects of land use on soil erosion, sedimentation, and flooding is the focus of this paper. Cumulative watershed effects that might not be apparent at any particular location or time, but when viewed in a downstream perspective can have significant impacts on people living downstream for a longer time period are also addressed. Institutional and policy considerations are discussed to place watershed management into a proper perspective.

Key words: Forestry, agroforestry, livestock, cropping, water quality, sedimentation, water flow, pollutants.

Conserving and sustaining water and other natural resources have historically been a concern of people living in the dryland regions of the world because of the often encountered "marginality" of availability of these natural resources. Water scarcity and the availability of other natural resources are likely more critical to a greater number of people living in dryland regions than those from the more humid regions of the world. According to a report from the Dialogue on Water, Food and Environment, a consortium of international organizations concerned with the world's water resources, about 2.7 billion people, nearly one-third of the world's population, will live in regions of acute water scarcity by 2025. The people of southern Asia and sub-Saharan Africa will be the most severely affected. Water will always be in a crucial balance in these arid and semi-arid environments and this balance is being upset at alarming rates over large areas by people and their land-use practices. These trends can be reversed through well conceived watershed management and better land stewardship. However, there are differing views about what watershed management means. We present a perspective of a watershed management approach to land stewardship that is oriented toward sustaining natural resource benefits that can realistically be obtained on watersheds in arid and semi-arid environments.

Meaning of Watershed Management

The definition and concepts of watershed management used in this paper are based largely on the definitions and concepts of Brooks *et al*. (1992, 1994, 1997), Gregersen *et al*. (1987, 1996), and the National Research Council (1999) of the United States. Watershed management is the process of organizing the use of land, water, and other natural resources on a watershed to provide necessary goods and services to people, while mitigating the impacts on soil and water resources. This approach recognizes the intrinsic interrelationships among soil, water, and land use and the connections between upland watersheds and downstream river basins. It incorporates soil and water conservation and land-use planning into a holistic and logical framework. This more encompassing approach is achieved by recognizing the positive and negative impacts on people that are caused by planned or unplanned interactions of water with other watershed resources. It is also necessary to appreciate that the nature and severity of these interactions are influenced by how people use these resources and the quantities of resources that they use. The effects of these interactions follow watershed boundaries, not political boundaries. Watershed management activities on the uplands of one political unit can significantly impact the people on a downstream political unit regardless of the respective land ownerships, often resulting in unaccep downstream or off-site effects.

A watershed management approach to land stewardship accommodates the interests of the widest possible number of people. The approach examines the benefits obtained from land stewardship by optimizing production and maintaining environmental integrity. It also facilitates more effective conflict resolution from a sustainability perspective. The approach further recognizes that future generations of people deserve to inherit landscapes that are capable of producing the needed goods and services while maintaining ecosystem health and economic stability (Gregersen *et al*., 1987, 1996, 2000). The following sections of this paper discuss how watershed management is implemented to conserve and sustain the flow of high quality water, wood production and other forestry activities, livestock production, and agricultural cropping and to mitigate effects of land use on soil erosion, sedimentation, and flooding.

Watershed Management Practices

Watershed management practices are planned changes in land use and vegetative cover and other nonstructural and structural actions that are made on a watershed to achieve ecosystem-based, multiple-use management objectives. Watershed management practices implemented in dryland regions are oriented largely toward rehabilitating degraded landscapes; protecting soil, water, and other natural resources on lands managed to produce food, forage, fiber, and other products; enhancing the flows of high-quality water from upland watersheds to downstream places of use; and providing people with valued amenities such as aesthetic landscapes. While many land uses can occur on watersheds, natural resources production and environmental protection are equally important managerial objectives.

Producing, Conserving, and Sustaining Watershed Resources

Watersheds provide a diversity of benefits to local inhabitants and to a greater number of people within the larger river basin through the flow of water and other natural resources off the watersheds. Inhabitants of watersheds manage their land for the production of forage, food, and fiber that they require to survive and generate income. Therefore, water, timber, forage, and other natural resources on the watersheds should be managed in the most economically efficient and environmental sound combinations possible to obtain the products, commodities, and amenities that people need (Fig. 1). Importantly, the consumption or otherwise use of the natural resources on upland watersheds must also be balanced with the needs of people living downstream and in the larger river basin. Upland watersheds are the headwaters of many large rivers in dryland regions. As a consequence, the proper management of watersheds is prerequisite to sustaining the flow of water that is necessary to maintain large-scale agricultural production within larger river basins. How these watersheds are managed is also crucial to sustaining the flows of other commodities and amenities that are necessary to the livelihood of the people living on the watersheds and to downstream residents.

High quality water

Water limits much of what people can do. Sustainability of high quality water supplies is critical to the welfare, and ultimately the survival, of people living in dryland environments. Therefore, emphasis of watershed management practices in drylands is placed on developing and conserving supplies of water for both upland and downstream uses. Numerous methods are used in developing water supplies in the absence of perennial streams or abundant groundwater. Water harvesting is one example. Water harvesting systems involving the collection and storage of rainfall until the collected water can be beneficially used have been used to provide water for livestock production or agricultural cropping for over 4,000 years in many dryland regions of the world (Chiarella and Beck, 1975; Mehdizadeh *et al.,* 1978; Vashistha *et al*., 1980; Thames, 1989). Interest in this technology continues to the present. Likewise, water spreading is a proven method of distributing intermittent water flows onto the landscape to enhance forage and crop production. Water harvesting and water spreading methodologies are used to both increase water supplies and productivity of the land that reduces the pressures of deforestation, overgrazing by livestock, and improper agricultural cultivation.

Water that is captured during periods of abundance can often be conserved for use at a later time through methods that reduce evaporation, transpiration, and seepage losses (Satterlund and Adams, 1992; Ffolliott *et al*., 1995b; Books *et al*., 1997; Chang, 2003). Methods of reducing evaporation from stock tanks and other small impoundments include covering these water bodies with polystyrene, rubber sheeting, or floating blocks of wax. Aliphatic alcohols and other liquid chemicals that form monomolecular layers on the water surface have been used to reduce evaporation on larger water bodies. Transpiration losses are reduced by replacing plant species that have

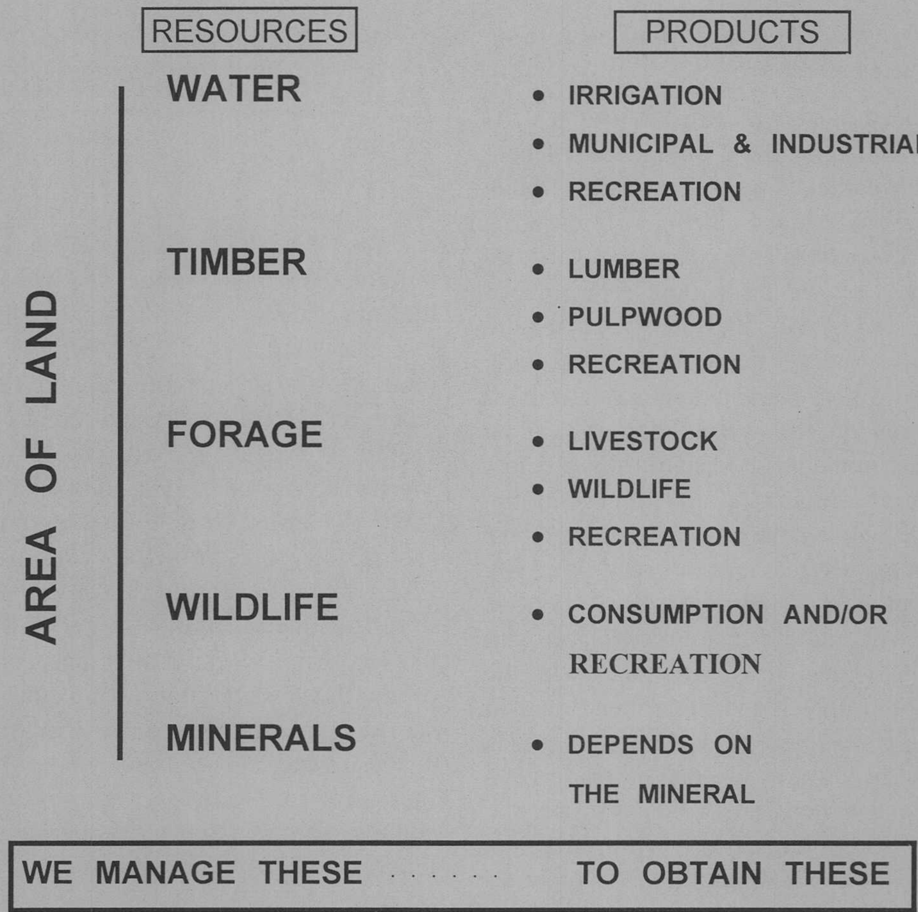

Fig. 1. Resources and products of human need (constructed after Ridd (1965), Ffolliott et al. (1995b) and Brooks et al. (1997).

high transpiration losses with species that have lower transpiration rates; removing plants with deep rooting systems that extract water from shallow water s; and applying anti-transpirants that either close stomata or form a film on leaf surfaces. Methods of reducing seepage losses from reservoirs and earthen canals constructed in pervious soils include the compaction of the soil within these structures; the treatment of the soil surface with chemicals to break up aggregates; and lining the canals and bottoms of small reservoirs with impervious materials. The latter method can be too expensive for large reservoirs, however.

There can be adequate water to meet local needs in some instances, but its quality might be such that it is not suitable for its designated uses. Available water supplies, therefore, must be considered in the context of water that is suitable for a designated use. The quality of water flowing from watersheds is affected by geological-soil-plant-atmospheric systems and land uses. Water flowing from watersheds that are maintained in a good condition is usually high in its physical, chemical, and biological quality and, therefore, suited to a wide array of uses (Black, 1991; Brooks *et al.*, 1997; Chang, 2003). The reverse situation is the case when watersheds are in poor condition. Watershed condition is a term that indicates the health (status) of a watershed relative to its ability to process rainfall into streamflow and the watershed's capacity for sustaining plant growth. Watershed management practices that maintain a watershed in good condition are those that sustain high rates of infiltration into the soil; do not contribute to excessive soil erosion; facilitate a relatively slow streamflow response to inputs of precipitation; and sustain baseflow between precipitation events on perennial stream systems.

Because evapotranspiration accounts for much of the disposition of precipitation falling on watershed lands, vegetative changes that reduce evapotranspiration rates on a watershed generally increase water flows from the watershed (Black, 1991; Satterlund and Adams, 1992; Brooks *et al.*, 1997; Chang 2003). Evapotranspiration is reduced by changes in the composition and structure of the vegetative cover on a watershed. Watershed studies worldwide have shown that water flows can be increased from 5 to 650 mm of pretreatment streamflow regimes when vegetation is converted from deep-rooted plant species to shallow-rooted species; a vegetative cover is changed from plant species with high interception capacities to species with lower interception capacities; or plant species with high transpiration losses are replaced by species with low transpiration losses (Bosch and Hewlett, 1982; Whitehead and Robinson, 1993). Increases of water flows from vegetation manipulations in dryland regions are at the lower range of the above reported increases. Hibbert (1979) showed that about 480 mm of annual precipitation is required for vegetation changes to cause significant increase in water flows in the western United States. He reasoned that precipitation below this minimal amount is effectively used by the residual forest overstory and subsequent increases in herbaceous plant cover on the watersheds. Maximum water flow increases of less than 100 mm annually have been reported for the dryland regions of the western United States (Baker and Ffolliott, 2000). The length of time into the future that water flows continue to exceed pre-treatment levels is influenced by the type of vegetation that regrows on the treated watershed and the rate of this regrowth.

Wood production and other forestry activities

Trees are a source of fuel, poles, and building material for watershed inhabitants. Many fruits, leaves, young shoots, and roots of trees can be valuable food reserves for people in emergency situations. Trees are a source of fodder for livestock and browse for wildlife at times when herbaceous forage in not available. Trees can be planted in home gardens and parks, buffer strips along streets and sidewalks, and greenbelts around cities and villages to improve local environmental conditions. Trees also play a vital role in maintaining the delicate ecological balance of arid and semi-arid environments. The roots of trees hold soil in place and control soil erosion and help to stabilize steep slopes. Trees retained in windbreak plantings protect the site from accelerated aeolian erosion, lessen evapotranspiration rates, and moderate air temperature extremes. Multipurpose tree species are ideal for protecting and often improving the fertility of soil while providing leaves and small branches for fodder without impairing agricultural cropping (MacDicken and Vergara, 1990; Hocking, 1993; Ffolliott *et al*.,1995a, 1995b). Multipurpose trees often fix nitrogen in the soil in addition to providing benefits to local people and their livestock. The issue confronting watershed managers is reconciling the needs of people living on the watersheds to harvest trees for fuel and other tree-based products with the ecological benefits obtain from the trees.

Trees in the woodlands and forests on watersheds in the dryland regions of the world have often been mined more than managed as a renewable natural resource; that is, trees have been exploited without concern for their renewal. Cutting trees in excess of the sustainable production level in response to the growing needs of expanding human populations is likely to lead to an irreversible downward spiraling of available wood resources. Converting woodlands and forests to grazing lands or agricultural croplands on sites that are not able to sustain livestock or agricultural production can cause a degradation of soil and water resources. Incidences of wildfire or inadequately controlled fire that is set by farmers to convert woodlands or forests to pastures or croplands can also damage soil structures and, as a consequence, increase soil erosion from the disturbed sites.

Applications of silvicultural treatments and forestry management practices to sustain wood production and other tree-based benefits presuppose a knowledge of the inherent characteristics of the trees, woodlands, or forests in question. This knowledge has not always been available in the dryland regions of the world. Forestry methods developed in the more humid regions of the world do not necessarily apply in dryland regions because of the inherently limited reproductive capacities, slow growth rates, and low yields of wood of the trees in these ecosystems. Nevertheless, ecosystems containing trees must be properly managed in the context of a watershed management approach to land stewardship to maintain growing stock levels. Much as been accomplished in this regard in recent years.

Natural and artificial reproductive methods, intermediate cuttings to achieve optimal tree growth, applications of fertilizers, and other cultural treatments have been incorporated into holistic silvicultural systems that are applicable to woodlands and forests of many dryland ecosystems (Weber and Stoney, 1986; Armitage, 1987; FAO, 1989; Ffolliott *et al*., 1995a, 1995b). Prevention and protection measures against fire, disease, and insect infestations are also known in many instances. People are recognizing the need to invest labor, time, and other resources in implementing these systems and measures. Increased knowledge of growth rates and yields of wood have also allowed rotational periods and cutting cycles to be identified for the sustainable use of many tree species valued for fuel, poles, and other products. Importantly, the length of these periods must be reconciled with the immediate priorities of people to use the trees in sustainable watershed management programs.

Livestock production

Maintaining livestock is a way-of-life of many rural societies that are indigenous to arid and semi-arid regions, and, therefore, implementation of proper livestock grazing practices is necessary to sustaining livestock benefits. Dispersed livestock grazing on open rangelands or, occasionally, confined livestock grazing in small pasturelands near homesteads is practiced. Many watersheds are able to sustain more than one type of ungulate, whether they are livestock or indigenous herbivores, with proper management of the lands that the animals graze. The production of milk, meat, or wool for a marketplace and, therefrom, higher economic returns to pastoralists is often obtained by grazing more than one type of livestock (sheep, goats, cattle, etc.) or combining management of livestock and indigenous wildlife species (Pratt and Gwynne, 1977; Jacobs, 1986; Holechek *et al*., 1998). Inclusion of sheep or goats with cattle, while complicating the management procedures, can increase total livestock production without adversely impacting the availability of forage, fodder, and water resources or the watershed condition (McLeod, 1990). In doing so, a better distribution of animals can also be achieved on the watershed, resulting in a more uniform use of natural resources.

Livestock production practices that lead to a degradation of watershed condition are most commonly the result of livestock overstocking, that is, allowing more animals to graze an area than is consistent with the area's capacity to sustain livestock production. Overstocking of livestock causes a loss of forage species and, as a consequence a lowering of livestock growth and development. Trampling by excess livestock compacts soil surfaces, reduces rainfall infiltration, and, therefore, increases overland flows and soil losses (Branson *et al*., 1981; Jacobs, 1986; Holechek *et al*., 1998). Poor choices of watering areas for the livestock grazing on open rangelands and the improper management of the adjacent areas can cause further damage.

A key to concurrently sustaining livestock grazing and flows of high quality water is retaining a vegetative cover on the watershed. The production of native forage and fodder species and naturally occurring water sources often meet these joint requirements on watersheds in good condition. On other watersheds, however, it might be necessary to remove undesirable (noxious) plants to favor the establishment and growth of more desirable forage species; improve forage and fodder production by seeding of species suited to the conditions encountered; or develop additional water sources by drilling wells, constructing water harvesting systems. Or building small impoundments to trap and hold runoff water that would otherwise be unavailable to livestock.

Attaining the goal of sustainable livestock production requires that the area to be grazed be stocked with the number of livestock that can be supported on a sustainable basis; that livestock grazing be permitted only during the proper (often rainy) season when adequate forage resources are available; that the livestock be distributed appropriately and not be allowed to concentrate along streams or other watering sites where they can cause soil erosion, sedimentation, or other pollution; and that the kind of livestock be stocked that are best suited to the condition of the watersheds (Pratt and Gwynne, 1977; Jacobs, 1986; Clary and Webster, 1990; Holechek *et al*., 1998). These managerial guidelines are necessary to sustaining a good condition of the watershed and preventing land degradation and desertification.

Agricultural cropping

Small-scale, often rain-fed, and dispersed agricultural cropping is another common land use on watersheds in dryland regions. While small in their individual contributions to the overall agricultural economy of a region, the aggregate production of all agricultural cropping on upland watersheds can be comparatively large (Altieri, 1988; Spedding, 1988; Ffolliott *et al*., 1995b). Depending largely on the capacity of the land to produce agricultural crops and the level of capital available to do so, either subsistence or commercial farming is practiced. The agricultural crops produced are utilized to meet the immediate needs of subsistence farmers, although the occasional surplus obtained might be sold at a marketplace. Large-scale commercial farming on upland watersheds is less common because of the likely need for large irrigation facilities, diversified marketplaces, and infrastructures of vehicles and roads for the transportation of managerial inputs and production outputs.

Small-scale farmers employ cropping systems that relate to the local climatological conditions, inherent soil capabilities, and their needs, abilities, and perceptions of agriculture in attempting to sustain themselves. Although agricultural cropping systems on watersheds in dryland regions are endless in their strategies and methods of implementation, they can be grouped into categories of settled agriculture and shifting cultivation for discussion purposes. Settled agriculture is practiced where soil fertility and precipitation and temperature regimes allow crops to be grown in place on a more-or-less continuous basis. One crop a year is usually grown when rainfall amounts are sufficient. Shifting cultivation involves farmers moving from one site to another on a watershed once the potential of soil to produce agricultural crops at subsistence levels on the original site is lost. At higher elevations, cycles of shifting cultivation often include clearing of trees on the site, a burning of the residual vegetation with the ash serving as fertilizer, and planting of the agricultural crops. When soil fertility declines to the point of limiting acceptable crop production, the farmer moves to repeat the cycle elsewhere, eventually returning to the original piece of land. As populations of people and their livestock increase, however, the lengths of fallow diminish, soil losses increase, and the productivity of the land declines.

Farmers often engage in agricultural cropping on watershed lands that could also be used to grow trees for fuel, other wood products, or forage and fodder for livestock production. Potential conflicts in land use can be encountered when this is the situation. However, small-scale agriculture can also be compatible with watershed management objectives when it is practiced only on the sites suitable for agricultural cropping, considering both the land's inherent productivity potential and the economic returns of practicing agriculture on the land. One way by which sustained agricultural cropping is achieved on a watershed-basis is through a geographic separation of agriculture from other land uses with the other watershed strata put to the use or uses to which they are most suited. Another option is to alternate or rotate agricultural cropping with other land uses of a watershed being managed to maintain water flows, forestry activities, livestock production, etc. This option can evolve into a shifting cropping system. A third option of achieving combined production, a concurrent and continuous use of a watershed for forestry activities, livestock production, agricultural cropping, and other land uses, is generally not feasible in dryland regions.

There are land use, vegetative, and engineering measures that are available to maintain or increase the productivity of watersheds in terms of small-scale agricultural cropping. Land use and vegetative measures include the establishment of windbreaks to protect sites vulnerable to excessive wind erosion; and alley-cropping and other agroforestry schemes to optimize site potentials and mitigate the risks of monocultures. Designating fallow periods of sufficient length of time to allow a recovery of the soil's fertility and, as a consequence, the land's productivity potential can also be necessary. Engineering measures for the same general purpose include the construction of bench or broad-based terraces, contour ditches, and gully control structures and protected waterways. Water harvesting, water spreading, and localized irrigation measures might also be considered.

Agroforestry

Forestry activities, livestock grazing, and agricultural cropping often occur in varying combinations within a watershed boundary. Watersheds in many dryland regions are mosaics of these and other forms of land uses. Some of the best opportunities for people to match their desired land uses with the capacities of a watershed to achieve productivity and benefits and, at the same time, attain downstream protection from flooding, sediment accumulations, and other cumulative effects involve the integration of agroforestry practices into a watershed management approach to land stewardship. Agroforestry is a system of land use where trees or other woody perennials are grown on the same piece of land as agricultural crops, livestock, or a combination thereof, either sequentially or simultaneously (Nair, 1989; MacDicken and Vergara, 1990; Gordon and Newman, 1997; Buck *et al*., 1999). As such, agroforestry practices are effective combined production systems and, therefore, have a bearing on sustaining the welfare of watershed inhabitants.

Agroforestry practices found on watersheds in dryland regions are mostly agrisilvicultural, silvopastoral, and agrosilvipastoral in their structure. Agrisilvicultural practices are combinations of agricultural crops and forestry activities with the agricultural crops dominating. Silvopastoral combinations are forestry activities and livestock production with a dominant land-use of forestry. Agro-silvipastoral practices include agricultural cropping, forestry, and livestock production in varying combinations of dominance. Arrangements of the components of agroforestry differ in space (random, alternate rows, or border-tree planting) and time (coincident, concomitant, or sequential). Agroforestry practices also differ in their function, that is, whether they function to produce one or more of the needs of people, ameliorate microclimates, retain soil and water resources, or combinations of these and other protective functions. Agroforestry practices are subsistence, commercial, or intermediate from a socioeconomic standpoint, depending on whether the outputs meet the basic needs of the people, are made available for sale at a marketplace, or a combination of the two.

Transportation routes

Roads, trails, and other transportation routes facilitate the movement of managerial inputs and production outputs. However, transportation routes located on steep slopes, on erodible soils, in narrow riparian corridors, or at stream crossings can disrupt the hydrologic functioning of a watershed and cause severe soil erosion, landslides on steep terrain, and channel degradation in many situations. These impacts often exceed those caused by all of the other land-use activities and management practices combined (Black, 1991; Satterlund and Adams, 1992; Brooks *et al.*, 1997; Bell, 2000). Up to 90% of the sediment produced can originate from roads and stream crossing (Egan, 1999; Grace, 1999; Chang, 2003). Roads and trails that lead to increased accessibility of remote watershed lands can also foster more rapid and often ill-planned human settlements and the accompanying exploitation and degradation of natural resources. It is imperative, therefore, that transportation routes are correctly planned, properly constructed, and continuously maintained to reduce these adverse impacts.

Cumulative Watershed Effects

Land-use practices occurring across the watershed have cumulative effects on the flows of water, sediment, and other pollutants. Cumulative watershed effects refer to those effects that might not be apparent at any particular location or time, but when viewed in a downstream perspective, the combination of effects of other land uses can have significant impacts on people living downstream for a longer time period (Sidle and Hornbeck, 1991; Reid, 1993; Brooks *et al.*, 1997; Stein and Ambrose, 2001). The following cumulative watershed effects are discussed in their context of upstream-downstream linkages.

Water flows

In contrast to the more uniform flows of perennial streams in humid climates, water flowing from watersheds in arid and semi-arid regions is likely to diminish as the distance between the upland watersheds and downstream sites increases. These reductions in stream water result largely from the cumulative effects of transmission losses in the channel systems, evaporation of water in route, and transpiration by riparian vegetation. Brown and Fogel (1987) reported that 50% of water increases from vegetative manipulations on the upland watersheds of the Verde River Basin in central Arizona would be lost before reaching downstream reservoirs 160 km away for these reasons. Regardless of the observed losses in streamflow, efforts to increase water flows to downstream sites through vegetation management on upland watersheds need to have adequate downstream storage that is located in close proximity to the manipulated watersheds.

There are a variety of land use, vegetative, and engineering measures to assure adequate supplies of usable water are sustained and to mitigate the occurrences of flooding, landslides, and other forms of soil loss on watersheds. The selection of the specific measures to implement on a particular watershed is largely dependent on the watershed condition, available technical and economic resources, and people's long-term goals for watershed management. Among the land use and vegetative measures that help to assure adequate supplies of usable water are available to people are encouraging the use of low water-consuming plant species in forestry activities, livestock production, and agricultural cropping whenever possible. Over 75% of the rain falling on dryland regions can be lost through evapotranspiration processes of plants (Brooks *et al.*, 1997; Unland *et al.*, 1998; Scott *et al.*, 2000; Chang, 2003). Therefore, there can be a potential for substantial water-savings when low water-consuming plants are incorporated into watershed management schemes. Water harvesting and water spreading systems, reservoir and water diversion structures, small-scale irrigation facilities, and properly spaced wells are engineering approaches to providing water that meets the needs of people. Developing alternative water supplies when the necessary water quality standards are not met is another option in some instances.

Land use and vegetative measures to reduce the devastating effects of infrequent, but often devastating flooding events on upland watersheds and larger river basins in dryland regions include maintaining vegetative covers to enhance the infiltration of flood waters and increase water consumption by plants on flood-prone areas. Water diversion structures, levees, gully control structures, and improving the capacity of stream channels to carry flood waters away from the impacted area are engineering measures that help in alleviating the damages incurred by flooding.

Maintaining vegetative covers along streambanks and other areas on a watershed that are susceptible to excessive soil erosion helps to ensure adequate water quality. Other land use and vegetative measures that help to maintain flows of high quality water include controlling discharges of human, livestock, and mining wastes into streams; retaining wetland ecosystems as secondary waste-water treatment systems; and establishing environmentally sound management guidelines for forestry activities, livestock grazing, and agricultural cropping on erosion-prone sites within watershed boundaries. Incidences of landslides on steep slopes are reduced by maintaining a good vegetative cover to promote the effective infiltration of rainfall; reforestation or afforestation with deep rooted plant species for soil stabilization; and restricting residence and production activities on the steeper uns slopes. Among engineering approaches considered for the same purpose are the construction of grassed waterways to minimize stream channel scouring, drop structures to control excessive overland flow, and benched terraces.

Sedimentation

Levels of sediment delivered to stream channels and reservoirs are frequently increased due to degraded watershed conditions. One objective of watershed management, therefore, is to reduce these excessive accumulations of sediment in channel systems and downstream reservoirs. Unfortunately, the relationships of upland soil erosion to downstream sedimentation processes are poorly understood for many large river basins, largely because knowledge of the impacts of watershed management practices on surface and gully erosion and soil mass movement is often incomplete (Black, 1991; Brooks *et al.*, 1997; Chang, 2003). It is known that downstream sedimentation results not only from upland soil erosion, but also from channel erosion and the mass movement of soil directly into the channel or reservoir. Channel characteristics and distances between the watersheds of interest and downstream reservoirs determine the quantities and timing of sediment delivery, adding complexity to the analysis of sedimentation in time and space.

Concentrations of sediment in the water flowing from watersheds might be comparatively low at the outset, but these concentrations can significantly increase as the water flows through tributaries of a larger river basin to downstream reservoirs or other places of use. It is imperative, therefore, that the streamside corridors throughout a river basin be managed in a manner that minimizes increases in sediment concentrations en route. One way to mitigate increases in sediment loads and other pollutants in the tributaries of a river basin is through the establishment and maintenance of buffer strips of vegetation along the waterways to filter out the sediment caused by off-site land-use activities (Brooks *et al.*, 1997). Buffer strips also serve to maintain streambank stability and provide shade and shelter for livestock, terrestrial wildlife and fish, and other aquatic organisms.

Other pollutants

Sustainability of high quality water flows is another benefit attributed to proper watershed management practices. Flows of high quality water to downstream users are usually associated with well-managed watersheds in good condition. These watersheds have relatively sparse densities of people, support comparatively few grazing livestock, and experience proper agricultural cultivation. However, improper use of upland watershed lands can lead to polluted water flows that impact downstream inhabitants and lead to adverse effects on aquatic ecosystems within larger river basins. Within the larger river basin, however, relating upland watershed management practices to downstream water quality is a difficult task and, in many instances, hindered by incomplete data and inadequate knowledge of functional relationships. Importantly, maintaining watershed in good condition also sustains the flow of high quality water to downstream users. Buffer strips established along the waterways also filter excessive nutrients that can occur in runoff water.

Institutional and Policy Considerations

A *river basin* is similar to a watershed in its definition, but it is much larger in its area. The Ganges River Basin in India, the Nile River Basin in Egypt, and the Colorado River Basin in the western United States include all of the lands that drain through these rivers and their tributaries into the ocean. River basins, therefore, encompass both upland watersheds and larger downstream catchments. Hydrologically speaking, key links connecting upland watersheds to larger river basins are the flows of water, sediments, and other pollutants from one to the other. However, because political boundaries do not influence the flows of water, sediment, and other pollutants, what is done on the watersheds of one country, one community, or one land owner can significantly affect the flows of water, sediment, and other pollutants to other countries, communities, or land owners occupying a downstream position. As a consequence, it is necessary to include off-site effects (externalities) in undertaking a holistic analysis of the benefits and costs of watershed management practices within a larger river basin.

Organizational restructuring is often needed to facilitate the cooperation and coordination of natural resource management within a river basin to mitigate cumulative watershed effects. The goals and objectives of management and regulatory agencies and the diverse interests of local people need to be integrated to achieve this purpose. To help in attaining this integration, a variety of watershed partnerships, watershed councils, watershed corporations, and other locally-led initiatives have emerged worldwide in recent years (Lant, 1999). Interactions among the social, political, and economic forces of land stewardship with the technical aspects of watershed management are effectively fostered through the activities of these organizations. Some of the organizations are forums for exchanging ideas, views, concerns, and management recommendations, while others are actively responsible for watershed and river basin management programs. The basic idea of these organizations is that all members of society have equal decision-making power.

Because political and tenure boundaries rarely coincide with natural watershed boundaries, political institutions seldom consider that watersheds are workable land management units for planning and action. Development professionals, agencies personnel, and local people are often unaware of the watershed management approach to land stewardship (Brooks *et al*., 1992, 1994, 1997; Quinn *et al*., 1995). This lack of awareness further limits the development and enforcement of policies that promote sound watershed management. At the same time, however, it is possible to overcome barriers to the adoption of policies that support watershed management. An increasing number of policy-makers recognize that environmentally sound practices, projects, and programs must allow for the interrelationships between land and water uses on watersheds to achieve conservation and sustainable use of these natural resources. They realize that ignoring the boundaries and interrelationships set by the forces of nature will repeat the environmental problems of the past.

Conclusions

Conservation and sustainability of natural resources are constantly threatened by a possibility of improper human interventions degrading the capacity of a watershed to support people's uses of the natural resources on the watershed. Some degradation of watershed lands occurs as a result of natural phenomena such as flooding, landslides, and wildfire. Watershed managers have little control over these events other than to maintain the best possible landscape conditions so that the impacted watersheds are able to withstand the consequences of these phenomena (Brooks *et al*., 1997; Abramovitz, 2001; Ffolliott *et al*., 2002). But, even with what seems to be environmentally sound land-use practices, the activities of people can inadvertently worsen the sources of degradation and, in doing so, make them central issues in the management of a watershed. It is imperative, therefore, that the inhabitants of watershed lands adhere to the "best possible form" of land stewardship.

The cumulative effects of human-induced land-use activities on watershed resources are receiving increasing attention throughout the world. These effects are largely manifested by changing water flow regimes; altered erosion-sedimentation relationships; and changes in water quality and aquatic ecosystems. An understanding of these effects requires a fundamental knowledge of hydrologic processes and watershed management within an interdisciplinary land stewardship perspective. For example, the protection, management, and, when needed, restoration of fragile streamside corridors will require that we learn more about the hydrologic function of these ecosystems. Research on hillslope processes and water movement through the soil body should lead to better watershed management to reduce detrimental effects of human-induced activities on runoff, sediment flow, and non-point source pollution. Even though research efforts continue to focus on the evapotranspiration process, it still remains the hydrologic process that we understand the least. These few examples of research needs indicate that many challenges remain in hydrology, watershed, and water resources management, and the efficient use of water in agriculture and other sectors. Hydrologists and watershed managers need to respond to these challenges with well-designed research projects that can yield better methods that advance hydrologic science.

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