

CONCEPTS AND PRACTICES IN REPLACEMENT OF WATER SOURCES
ON RECLAIMED MINED LANDS¹

David W. Simpson² and M. K. Botz, P.E.³

Abstract. — Establishment of water sources on reclaimed mined lands may be required to support post-mining land uses. Options for providing water include impoundments, wells, water harvesting and transport. An understanding of precipitation-runoff relationships, consideration of water losses and recognition of legal constraints are essential to planning and design of impoundments. A case study at the Absaloka Mine is described, and options for increasing runoff for beneficial use are discussed.

ACKNOWLEDGEMENTS

The information presented in this paper is the product of work conducted over several years by numerous individuals within the Westmoreland and Hydrometrics organizations. The authors would like to acknowledge particularly the contribution of James R. Gilley, who refined the hydrologic data base and developed the runoff predictions and pond designs. In addition, Richard Clausen, Robert Miller, Mathew S. Tudor and Jack D. Cline also contributed significantly to collecting baseline hydrologic data and developing the concepts of water replacement. The authors also would like to thank DeAnne Malnaa who prepared the manuscript.

INTRODUCTION

In the Northern Great Plains, availability of water is a key element in the use of land for grazing of livestock. With the exception of major valley bottoms where water in perennial streams is consistently available, development of water sources has been necessary to maximize the utility of grazing land. Such water developments have benefitted wildlife as well.

Large scale surface mining of coal in the Northern Great Plains has focused a great deal of interest on reclamation of mined lands. Although specific requirements of individual states may vary, all are guided by the Surface

Mining Control and Reclamation Act of 1977, which establishes national performance standards for reclamation of mined lands. Among the requirements are restoration of land use capability [Sec. 515(b)(2)], minimization of disturbances to the prevailing hydrologic balance [Sec. 515(b)(10)] and protection and enhancement of fish, wildlife and related environmental values [Sec. 515(b)(25)]. If the capability of grazing land is to be restored after mining, and if disturbances to the hydrologic balance and to fish and wildlife are to be minimized, reclamation plans must include constructed water developments where necessary to support the post-mining land use.

Westmoreland Resources, Inc., has operated the Absaloka Mine in Big Horn County, Montana, since 1974. As of January, 1985, 2347 acres were permitted for mining disturbance, of which 1180 acres had been disturbed by mining and mining related activities. Total coal shipments to date have exceeded 45 million tons. The mining method is area stripping using draglines. The current production rate is about four million tons annually.

In June, 1983, Westmoreland Resources, Inc., filed a revised application to expand the area of mining operations by 573 acres in order to maintain production. The application area included several developed springs which serve as sources of livestock water. Early in the review process, the Montana Department of State Lands (DSL) determined that replacement of livestock and wildlife water would be a necessary component of the reclamation plan. In response to this determination, Westmoreland, in cooperation with Hydrometrics, Inc., evaluated the feasibility of providing permanent post-mining water supplies, and developed a detailed water replacement plan as part of the

¹Paper presented at the National Meeting of the American Society for Surface Mining and Reclamation (Denver, Co., October 8-10, 1985)

²General Manager, Operations; Westmoreland Resources, Inc., Hardin, Mt.

³President; Hydrometrics, Inc.; 2727 Airport Road; Helena, Mt.

proposed reclamation program. This process included a review of the water needs of livestock and wildlife, identification of alternative means of providing water, detailed examination of technical and legal aspects of constructing permanent impoundments, and finally, development of plans based on site specific hydrologic data. These plans were approved and a permit was issued in January, 1985.

POST-MINING WATER NEEDS

Published information on livestock water needs shows considerable variability depending on weather conditions and dryness of forage. According to Stoddart et al. (1955), horses require 10 to 12 gallons, cattle 6 to 10 gallons and sheep 0.4 to 1.5 gallons daily. Water requirements may be considerably greater when the temperature is high and humidity low, and cattle may require 15 to 20 gallons daily in very hot, dry weather as commonly experienced in the region. Consumption of water by wildlife is small compared to livestock use. Mule deer have been reported to consume 0.4 gallons daily (Smith 1954); antelope require .25 to 1 gallons daily (Yoakum 1984). Although wildlife use of water is likely to be small, large concentrations of wildlife, particularly during summer when water needs are greatest, may be a consideration in post-mining water developments.

Spacing between water sources depends on topography, range capacity and range management practices. No more than 50 animal units per watering facility is a common practice (Heady 1975). Although water is an important regulator of grazing distribution, close spacing may contribute to overuse of range (Bell 1973). Practical travel distances to water for cattle are one-half mile in very steep, rough country, one mile in rolling, hilly country and two miles in smooth, flat country (Bell 1973; Stoddart et al. 1955); spacing therefore should be one to four miles, depending on topography. On highly productive range or pasture, one or even two water sources per section may be optimal (Vallentine 1971). For wildlife, a spacing of one to five miles between water sources is recommended for antelope, and two to three miles for mule deer (Camenzind 1983).

WATER SUPPLY OPTIONS

Impoundments

Impoundments to capture surface runoff may be constructed as dams or excavations, and undoubtedly represent the most common type of water development facility in the region. The Soil Conservation Service has assisted landowners in the construction of ponds for many years, and it is estimated that there are more than 220,000 such structures in the region (Bue 1964).

Rosso (1979) emphasized the practical advantages of interior ponds and depressions,

including the establishment of post-mining water supplies for livestock and wildlife. Numerous authors have noted the importance of impoundments on reclaimed land to wildlife species, particularly in the West (Harju 1980; Yoakum 1984; Camenzind 1983; Jackson 1984; Parr and Scott 1983).

Prior to the enactment of federal and state legislation requiring reclamation of mined lands, ponds commonly developed in abandoned coal mine areas. Gwynn (1966) and Wollenhaupt and Richardson (1982) noted the occurrence of ponds on abandoned coal mine sites in western North Dakota. Aquatic habitat values of coal mine ponds in the Northern Great Plains were reported by Hawkes (1978). Goering and Dollhopf (1982) studied the hydrology of an impoundment at the Peabody Big Sky Mine in Southeastern Montana.

Parr and Scott (1984) described four types of impoundments which have been developed at coal mines in the Midwest - final pit, depressions in regraded spoil, sedimentation ponds and slurry ponds. In addition to collecting surface runoff, final pit impoundments may intercept the underlying ground water system. Depressions may be constructed in regraded spoil to develop shallow ponds for wildlife habitat enhancement. Sedimentation ponds may be retained as permanent impoundments provided applicable regulatory requirements are met. A fourth type of impoundment may be developed from reclaimed slurry ponds. Since coal washing is not commonly practiced in the Northern Great Plains, there is little opportunity to reclaim slurry ponds.

Wells

Baseline studies of hydrogeologic conditions will determine potential for ground water development by wells completed below the lowest stratigraphic level of mining disturbance. In some cases, replaced spoils may resaturate sufficiently to serve as a source of groundwater. Water yield requirements depend on range management practices and storage facilities, but 1000 gallons per day is probably minimal, assuming 50 animal units in hot, dry weather. Well depth and other design details will depend on site specific conditions.

The choice of pumping systems should consider general practices in the area as well as pumping methods used prior to mining. Windmills may be suitable, or submersible electric or gasoline powered pumps may be preferred where winds are less consistent. Solar-powered electric pumps have recently become available for use in remote locations, but little information is available on reliability and useful life.

Where water can be provided reliably from wells, their use may be preferable to constructing ponds, which necessarily depend on seasonal runoff.

Water Harvesting

Water harvesting involves the process of collecting natural precipitation from prepared watersheds for beneficial use (Myers 1974). The practice of water harvesting is centuries old (Frasier 1980; Myers 1974), and continues in modern times throughout the arid and semi-arid regions of the world. In the United States, development of water harvesting technology has occurred primarily in the southwest, with only limited application in the Northern Great Plains.

Rainfall catchments may consist of natural rock or clay surfaces, compacted or mechanically treated soils, or other surface treatments. Chemical treatments such as sodium salts, sealers, repellants, waxes and petroleum products, have been investigated. Soil coverings, including sheet metal, concrete, asphalt, reinforced asphalt, and polymer membranes have been used in water harvesting systems. Virtually every conceivable material has been utilized in catchment construction. Excellent summaries of water harvesting technology include Cluff and Frobel (1978) and Frasier and Myers (1983).

Use of water harvesting techniques for water replacement on reclaimed mined lands in the Northern Great Plains is likely to be limited by cost, maintenance requirements and useful life. Artificial catchments are subject to damage by puncturing of surfaces by large mammals, rodent holes, plant growth, wind and deterioration of materials. Chemical treatments typically require frequent re-application to maintain performance.

Despite disadvantages of cost and durability, water harvesting concepts may be feasible at some sites. Runoff may be enhanced by surfacing watersheds with less permeable soils. Compaction of soils may be desirable in some circumstances to enhance runoff. Smaller water harvesting developments for wildlife use may be suitable in some cases.

Transport

Haulage of water for livestock is likely to be a last-choice option. It may be possible, however, to transport water to reclaimed areas by pipeline, particularly if there is an opportunity for gravity flow. Site specific conditions will dictate the feasibility of pipeline transport, depending on water availability, distance, cost of construction, maintenance costs and practices in the area.

FEASIBILITY OF IMPOUNDMENTS

Construction of impoundments as part of a reclamation plan is an attractive option. Familiarity as a common ranching practice, minimal maintenance requirements and wildlife habitat benefits are primary considerations.

The concept of impoundment construction is simple; runoff from a watershed is captured and retained for use during water-short periods. Implementation of this concept, however, is far from simple because the necessary technology has not been developed for use on reclaimed lands. Conventional reclamation planning has as a primary goal the control of erosion by minimizing runoff. Since adequate runoff is the critical factor in designing a permanent impoundment, it is necessary to understand precipitation-runoff relationships. Seepage control is a major concern in impoundment design, and geotechnical aspects of constructing impoundments on unconsolidated spoils are poorly understood. Evaporation rates in the region are high, and losses are likely to be significant. Quality of impounded water must be suitable for the intended use. In addition, a variety of regulatory constraints must be addressed.

Watershed Yield

Runoff is a highly complex process, and is functionally related to numerous climatic and physiographic factors. Chow (1964) and Haan et al. (1982) discussed these factors in detail. Precipitation type, intensity, duration, time and areal distribution, and antecedent soil moisture, are climatic factors of importance. Physiographic factors such as watershed size, shape, slope, aspect, elevation and drainage density; physical factors including land use, vegetative cover, infiltration condition, soil type, geology and surface storage; and channel characteristics directly affect the volume and rate of runoff. Small drainage areas behave differently from large drainage areas due to channel storage effects. In a small basin, overland flow rather than channel flow tends to dominate, and sensitivity to high-intensity rainfalls of short duration and to land use is not suppressed by channel characteristics (Chow 1964). Since reclaimed watersheds are likely to be comparatively small, the effect of basin size on runoff is of major importance.

Efforts to predict runoff from reclaimed watersheds have focused primarily on events of 10-, 25-, and even 100-year recurrence, for the purpose of designing open channels and sedimentation ponds. The Rational Formula (Linsley et al. 1949) and the Soil Conservation Service Technique (SCS 1972) are based on generalized assessments of watershed conditions, and are used widely for this purpose. Unfortunately, these techniques provide little guidance in designing a perennial water supply impoundment. Although numerous predictive models for runoff rate and volume have been developed (Haan et al. 1982; Fleming 1971; Fogel 1971), modeling efforts have not been directed toward reclaimed watersheds resulting from coal mining in the Northern Great Plains.

Empirical data on water yield from small watersheds in the Northern Great Plains is limited to a very few studies. Culler (1961) studied the hydrology of the response of stock

reservoirs to summer precipitation in the Upper Cheyenne River Basin of northeast Wyoming and western South Dakota. Based on four years of headwater runoff into stock dams, it was concluded that summer runoff was 2.9 percent of total annual precipitation, compared to 1.6 percent from the 8710 square mile basin as measured at Hot Springs, South Dakota. In all, 71 ponds with drainage areas ranging from 0.02 to 10.9 square miles were monitored, resulting in 212 station-years of record.

Sufficient data were provided to examine ponds with watersheds of two square miles or less on the basis of summer precipitation and runoff only. For 61 such ponds, the average summer runoff was 0.56 inches, or 6.5 percent of summer precipitation, while summer discharge at Hot Springs was 1.5 percent of summer precipitation. Using this analysis, headwater runoff was more than four times the discharge recorded from the drainage basin as a whole, presumably as a result of channel losses in lower reaches.

Neff and Wight (1983) studied precipitation-runoff relationships on 16 two-acre micro-watersheds in southeast Montana. Saline upland and claypan range sites were examined; both sites had clayey soils. Slopes ranged from one to five percent, and half of the watersheds were contour furrowed for moisture conservation. Average annual precipitation during this 12 year study was 14.5 inches. Results of this study (Table 1) showed relatively large average water yields, presumably due to clayey soils. These data illustrate the influence of land use factors and the importance of snowmelt to total runoff.

Table 1.—Runoff From Small Watersheds in Southeastern Montana (Derived From Neff and Wight 1983)

	Saline Upland Site	
	Undisturbed	Furrowed
Average Runoff (in.)	5.7	2.0
Average Runoff (%)	39.3	13.8
Average Snowmelt Runoff (in.)	1.7	1.4
Snowmelt Runoff - % of Total	30.0	55.0
	Claypan Site	
	Undisturbed	Furrowed
Average Runoff (in.)	4.0	2.0
Average Runoff (%)	27.6	13.8
Average Snowmelt Runoff (in.)	1.7	1.4
Snowmelt Runoff - % of Total	40.0	75.0

In their study of a 90-acre watershed near Newell, South Dakota, Hanson et al. (1974) reported a 15-year average annual runoff of 2.38 inches or 15.5 percent of the average annual precipitation of 15.4 inches. Due to steep slopes and clayey soils, this was higher than that of nearby watersheds which averaged 1.5 inches (10 percent). At least a small amount of snowmelt runoff was recorded in all years; the average was 1.0 inch, or 42 percent of the total annual runoff.

Published information regarding measured runoff from reclaimed watersheds in the Northern Great Plains is scanty. Goering and Dollhopf (1982) monitored runoff from a small regraded spoils watershed of 3.7 acres. Runoff during 1981 was 5.85 percent of precipitation, or 0.71 inches. These spoils had been reclaimed prior to requirements to replace topsoil, and revegetation was relatively sparse (Dollhopf pers. comm.).

Dollhopf and Goering (1982) reported runoff and sediment yield measurements from 0.9-acre reclaimed micro-watersheds at five mines in the Northern Great Plains. Five surface manipulation treatments were examined at each site, with the objective of minimizing runoff and erosion. Runoff from the topsoiled-chiseled treatment averaged 7.8 percent. This treatment is probably typical of reclamation practices in the region. It was noted that application of topsoil resulted in significantly reduced runoff; average runoff from nontopsoiled-chiseled spoils was 11.1 percent.

Clearly, runoff varies widely from basin to basin due to watershed factors, as demonstrated by the reported range of 2.9 to 39.3 percent. Although it is impossible to generalize, it seems reasonable to assume that actual runoff from a given reclaimed watershed will fall within this range, with variations from year to year resulting from climatic factors. It is evident that snowmelt is a significant proportion of total annual runoff.

Seepage Control

Impoundments constructed on regraded spoils will experience seepage losses that are directly related to the hydraulic head in the impoundment and to the permeability of the impoundment bottom. Spoils placed by dragline are normally poorly consolidated, have large void spaces, and have permeabilities as high as 10^{-4} cm/sec. The permeability results both from primary porosity of the earth material and secondary permeability created by dragline emplacement. Such spoils are subject to consolidation when wetted and can experience subsidence and piping. Dragline spoils in both North Dakota and southeastern Montana have experienced subsidence as a result of ponding of water.

Permeability of spoils handled by truck and shovel or by scraper is variable and is related

to compaction received during handling. Haul roads can become well compacted with permeabilities reduced to 10^{-6} cm/sec. or less in some soil types.

Dedrick (1974) summarized a variety of options for seepage control in impoundments designed for storage of harvested water. Spoil characteristics, the degree of seepage control desired and economic considerations will be criteria for designing seepage control measures. These may include compaction of natural soils, use of bentonite as a soil amendment, asphalt, polymer membranes, or even soil cement or concrete. Some spoil materials, particularly those containing abundant montmorillonite clays, may be suitable for impoundments without additional seepage control measures.

Sedimentation basins constructed adjacent to mined areas may be retained as permanent impoundments. These structures commonly are located very close to mined areas in unmined drainage bottoms so that all runoff from adjacent mining is collected. Once mining and reclamation are completed, runoff from the reclaimed watershed is impounded. If such a sediment pond is to be retained as a permanent impoundment, the location and design must incorporate considerations for seepage control.

In the case of a final pit impoundment, measures to control seepage may not be necessary, since the coal seam underclay will serve as the pond bottom. If a post-mining groundwater table develops, the final pit impoundment may have a reasonably constant water level.

Evaporation Control

Although various means of suppressing evaporation have been investigated with varying degrees of success (Cooley 1974), the most obvious and practical approach is the minimization of surface area. Steepness of banks will necessarily be limited by soil stability and at least one slope must be 4h:1v (25 percent) or flatter to allow access by livestock (BLM 1964). In the case of a final pit impoundment with the bottom beneath the water table, evaporation losses may not be a concern, and development of shallow areas for wildlife habitat enhancement may be possible. Water balance and effects of evaporation on water quality may be constraints.

Water Quality

In replaced water supplies, water quality must be suitable for the post-mining use. Livestock water quality criteria are in Table 2.

It is assumed that wildlife water quality requirements will be similar to livestock.

Table 2.—Recommended Limits For Livestock Water

<u>Parameter</u>	<u>Concentration - mg/l</u>
NO ₃ + NO ₂ as N	100
Total Dissolved Solids	3000-5000
Boron	5
Aluminum	5
Arsenic	0.2
Cadmium	0.05
Chromium	1.0
Cobalt	1.0
Copper	0.5
Fluoride	2.0
Iron	No recommendation
Lead	0.1
Mercury	0.010
Selenium	0.05
Sulfate	2500
Vanadium	0.1
Zinc	25

- Sources: 1. U.S. Environmental Protection Agency, 1976. National Interim Primary Drinking Water Standards.
 2. U.S. Environmental Protection Agency, 1976. Quality Criteria for Water.
 3. U.S. Environmental Protection Agency, 1973. Water Quality Criteria 1972. EPA-R-73-023.
 4. American Fisheries Society, 1979. A review of the EPA Redbook; Quality Criteria for Water. Bethesda, Maryland. 312 pp.

Acidic drainage from eastern and midwestern coal mines is common due to oxidation of iron sulfide (Olson 1981). In the Northern Great Plains, however, alkaline conditions predominate. A controlling factor in post-mining water quality is the source of water. Groundwater in resaturated spoils generally will have a quality significantly poorer than pre-mining groundwater (Van Voast et al. 1978).

Impounded water resulting from runoff of rainfall and snowmelt will be of good quality due to minimal opportunity for dissolution of soluble materials from soils. Increased mineralization may result from contact with soils present in impoundments or contributions of ground water to ponded water. Evaporation will increase the concentration of dissolved constituents, and the relationship between evaporation and seepage losses will control the degree of mineralization.

Rumble (unpublished report) examined 20 surface mine impoundments in North Dakota, South Dakota and Wyoming. Water quality in these impoundments was variable with sodium, calcium, magnesium, sulfate and bicarbonate the major ions in solution. Generally, water in these impoundments was suitable for livestock. Total

dissolved solids, lead and sulfate were reported to exceed recommended limits for livestock in a few ponds.

In a study of a coal mine pit impoundment in southeastern Montana, Goering and Dollhopf (1982) examined water quality. Surface runoff into the pond had a low TDS (429 mg/l average), and typically was a calcium or magnesium sulfate type water. Impoundment water showed similar chemical characteristics, with TDS values ranging from 210 to 2409 mg/l. Metal concentrations were low, presumably due to reduced solubility typical of metals under alkaline conditions. Data collected over a six-year period suggested a general improvement in water quality, with TDS levels stabilizing between 1000 and 1500 mg/l. Impoundment water quality was suitable for livestock use.

Legal Considerations

Impoundments on reclaimed mined lands although not prohibited, have been strongly discouraged by the legal structure. Requirements to grade to approximate original contour dictate that the regraded area drain without ponding of water. Similarly, regulations requiring elimination of highwalls virtually preclude construction of final pit impoundments. Discharges from impoundments must meet applicable water quality standards established by the Environmental Protection Agency and the Office of Surface Mining.

In order to obtain authorization to construct a permanent impoundment, a complexity of requirements, specified in Section 515(b)(8) of the federal Surface Mining Control and Reclamation Act must be met. These include demonstrations of adequate size, stability, suitable water quality, a reasonably stable water level, adequate safety and access for water users, and lack of conflicts with other uses of water. Requirements at the state level may vary somewhat, but in any case, construction of permanent impoundments on reclaimed land are required to meet certain minimum standards through a demonstration of compliance in the application for a mining permit.

Prior to construction of developed water supplies, water rights must first be secured. The western states all have similar water right restrictions in the sense that it is necessary to demonstrate that proposed activities will not harm existing water rights. For this reason, it is prudent to research existing water rights prior to mining in order to identify potential conflicts. Conflicts regarding ground water are much less likely than where surface water is involved. For this reason, wells may be preferable to surface water impoundments where surface water is overappropriated.

WATER REPLACEMENT PLAN FOR ABSALOKA MINE

The process of developing an acceptable plan for water replacement included three

submittals to DSL over a two year period, lengthy discussions with agency personnel, and thorough evaluation of options by Westmoreland and Hydrometrics. Standards of performance to be achieved included a dependable source of water for livestock, and perennial availability of water for wildlife.

Livestock Water Needs

Re-established water sources will serve an aggregate area of approximately 900 acres of reclaimed grazing land. Based on ranching practices in the area and vegetation sampling data from reclaimed lands, reclaimed rangelands are expected to support up to 300 animal unit months of grazing annually. Assuming a maximum water requirement of 20 gallons per day per animal unit in hot, dry weather, livestock may require as much as 180,000 gal; or about 0.5 acre-feet of water annually.

It is unlikely that it will be necessary to serve more than 100 animal units at any one time. Topography will be rolling hills, and two livestock water sources approximately one mile apart will be adequate to support the post-mining land use.

To assure dependable sources of livestock water on reclaimed land, two wells will be installed. Wells will be completed in bedrock to 100 feet beneath the lowest coal seam to be mined. Based on aquifer testing prior to mining, these strata are capable of producing sustained yields of five to ten gallons per minute or more. Quality is suitable for use as livestock water, with TDS levels ranging from 1400 to 3500 mg/l.

Perennial Surface Water

Development of a plan to provide perennial surface water for wildlife presented two very challenging problems. First, it was necessary to develop predictions of runoff from a reclaimed watershed of approximately 752 acres. Second, impoundment design would be required to retain water for long periods, with measures to control seepage and minimize evaporation.

Runoff predictions. Absaloka Mine is located in the Sarpy Creek drainage, which has a total drainage area of 453 square miles. The U.S. Geological Survey has maintained a gaging station near the mouth at Hysham, Montana, since the 1974 water year. The ten-year data record provides valuable information regarding the magnitude and statistical nature of runoff in the drainage (Table 3).

Table 3.—Precipitation - Runoff Statistics For The Sarpy Creek Drainage Based on Ten Years Of Records

	Precipitation (inches)	Runoff Equivalent (inches)	Water Yield (percent)
Maximum	25.30	0.603	4.51
Average	15.03	0.213	1.42
Median	14.38	0.092	0.73
Minimum	9.10	0.045	0.37

Westmoreland began continuous monitoring of surface water discharge in mid-1980, utilizing a network of nine stations. A complete review of the data is beyond the scope of this paper, but based on similarity of watershed factors, data from one of these stations, the "East Coulee" station, is considered most representative of reclaimed watersheds, and is summarized here (Table 4). Runoff was generally similar to that recorded for Sarpy Creek, with higher runoff in East Coulee in two of the three years of record. It is interesting to note that 1981, 1982 and 1983 values for Sarpy Creek are representative of minimum, average and median years, respectively, based on the ten-year period of record for that station (Table 3). At the "East Coulee" station, virtually all recorded runoff occurred in response to late winter thawing and snowmelt.

Table 4.—Summary of Runoff Data For The East Coulee Drainage (3311 Acres)

	Water Year			
	1981	1982	1983	1984
Precipitation (in)	12.30	18.68	12.91	13.16
Runoff (Acre feet)	9.0	65.9	51.6	23.2
Runoff Equivalent (in)	.033	.239	.187	.084
Water Yield (percent)	0.27	1.28	1.45	.064
Sarpy Creek Runoff Equivalent (in)	.045	.179	.102	.047

Short-term runoff records for "East Coulee" confirmed similarity with those of Sarpy Creek. Because the period of record is longer, it was decided to base estimates of average, median and ten-year minimum runoff from reclaimed watersheds on the Sarpy Creek values as listed in Table 3. This approach was considered conservative due to differences in watershed size, and the greater channel losses in the larger drainage. Additionally, for the purposes

of developing a water balance model for the impoundment, all runoff was assumed to result from snowmelt in late February, with no inputs from spring and summer precipitation. It is likely that on small reclaimed watersheds, spring rainfall will result in some runoff.

Impoundment Design. Storage of runoff in an impoundment will utilize a sedimentation pond dam constructed adjacent to the mined and reclaimed area. Design of the impoundment involves a "pond within a pond." To minimize evaporation, a small steep sided deep pond is placed in a larger shallow pond having a sloped access for livestock. As shown in Figure 1, this configuration allows storage of considerable runoff yet retains water well due to minimum exposure of water surface to evaporation at low pool elevations. Use of a siltation dike will minimize sediment accumulation in the pond bottom.

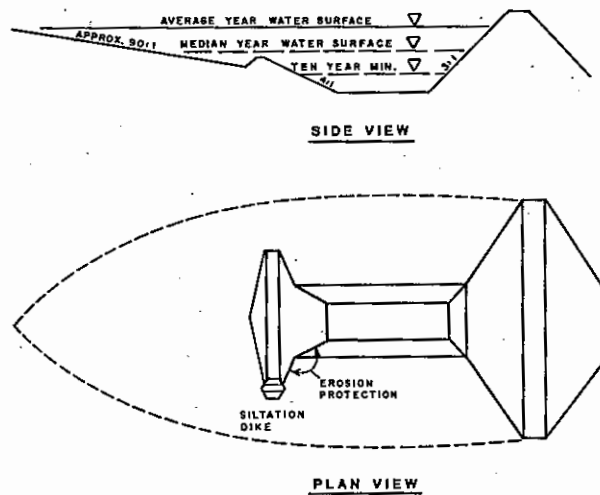


Figure 1.-- General Pond Design.

An important step in the design process was development of an incremented mathematical model to simulate the pond water balance. The model (called FONDBAL) was written in BASIC computer language and provided for loss of water by seepage and evaporation. Livestock consumption was small compared to seepage and evaporation was not incrementally simulated in the program.

Assumptions in the program are:

1. Pond inflow originates completely from spring snowmelt. Runoff volumes resulting from snowmelt in average, median and dry years are computed from actual runoff data.

- Seepage from the pond through the low permeability pond bottom was in accordance with the modified Darcy relationship (Walton, 1972).

$$Q = \frac{KHA}{M}$$

Q = Seepage in gallons per day; K = Bottom permeability;
H = Head on bottom; A = Pond area; M = Bottom thickness.

- Pond evaporation is assumed to be equal to measured pan data. The evaporation estimates beginning March 1 were developed from the average of 1980 and 1981 data collected at the mine site (Table 5):

Table 5.—Average Weekly Net Evaporation at Absaloka Mine.

Week No.	Evaporation Rate ¹ (in/week)
0 - 5	0
6 - 9	0.5
10 - 13	0.62
14 - 18	1.79
19 - 22	2.22
23 - 27	2.06
28 - 31	1.48
32 - 36	0

Total seasonal evaporation = 38.5 inches

¹ Evaporation data were not available for March, April and October. March (weeks 0-5) and October (weeks 32-36) evaporation were assumed to be offset by precipitation. April rates are estimated to be 75 percent of May values.

- Due to the large total capacity of the pond, snowmelt runoff would occupy only a small portion of total pond capacity and surface discharge from the pond was assumed not to occur.
- Pond configuration is an inverted truncated pyramid. Side slopes of the pond can be varied but were designed at 3h:1v. Upstream or end slopes of the pond are also variable but were designed at 4h:1v for maximum water retention.

Initially, FONDBAL computes the pond surface area from the stage-storage relationship. Seepage is computed using surface area, depth, bottom permeability and thickness. Evaporation is computed using the surface area and the evaporation table. The volume of water lost to evaporation and seepage during a one week period is subtracted from the total pond volume and a new volume, head and pond top dimensions are computed. With new values, the

next one week iteration is calculated and calculations continue for a 36 week period from March 1 through October 31.

The program also can compute a water balance for other complex pond configurations including different shapes, permeabilities and/or bottom thicknesses.

A key factor in impoundment design is the permeability of the pond bottom. Permeabilities greater than 10^{-6} cm/sec result in high seepage rates and significantly reduce the time water can be stored. To achieve a permeability of 10^{-6} cm/sec, pond bottoms and sides must be composed of selected soils and compacted to nearly maximum density. This will require engineering control in construction of the pond to ensure design permeabilities are achieved.

Quality of impounded water is projected to be suitable for use by livestock and wildlife. Because seepage (4.29 acre-feet) will exceed evaporation losses (2.17 acre-feet) in the median year, excessive concentration of dissolved solids due to evaporation will be prevented.

DISCUSSION

Replacement of water supplies is perhaps the most challenging aspect of mined land reclamation in the Northern Great Plains. Because the science of reclamation has focused primarily on revegetation and control of erosion, opportunities to enhance runoff for beneficial use have been largely ignored, and may at times conflict with conventional reclamation objectives. In addition to providing drinking water, wildlife habitat enhancement is frequently cited as a justification for water developments on reclaimed lands, but the need to conserve water may seriously limit the available options.

Watershed Design

In the short-term, erosion control is vital to the successful establishment of vegetation. In the long term, however, extreme measures to minimize runoff may severely limit opportunities for collection and beneficial use of runoff. If water development is to be a reclamation objective, then runoff management considerations must be incorporated into the reclamation plan. It is possible to control various watershed factors in order to increase water yields. It is also likely that measures to increase runoff will conflict with revegetation objectives or other legal requirements for reclaimed land.

Geomorphic Factors. Watershed size, shape, slope, and orientation are factors which may be controlled in a reclamation plan to promote runoff. Obviously, there will be constraints imposed by pre-mining topography and spoil

Wildlife Habitat Options

volumes, and in any given situation, certain of these factors will be subject to a greater degree of control than others. Conflicts with requirements to regrade to approximate original contour may limit runoff enhancement options as well.

Total runoff will increase with greater watershed size, but the relationship is not linear (Chow 1964). Channel losses in larger watersheds result in progressively lower runoff per unit area, other factors being equal. The shape of a watershed tends to affect discharge characteristics as well, with a more circular basin shape resulting in more sharply peaked flood discharge (Chow 1964). Presumably, this phenomenon also is an inverse function of channel length.

Slope of a watershed has a profound effect on runoff. Regraded slopes are subject to wide latitude in the regrading process, but approximate original contour requirements may place limitations on steepness. In any case, steepness of regraded slopes and channels must be constrained by stability considerations, in the absence of other factors dictating gentler slopes.

Orientation of a drainage may affect runoff due to exposure effects. Reduced evaporation and greater snow accumulation on north and east slopes render these aspects generally more favorable for watershed development.

Physical Factors. Physical factors also are subject to some control in the reclamation process. The most important of these include soil type, vegetative cover, land use, and surface storage.

It may be feasible to place less permeable topsoils in locations where higher runoff is desired. Such soils are likely to support less dense stands of vegetation as well, further increasing watershed yield. It is possible that such measures may cause difficulties in attaining revegetation performance standards, however.

Land use factors must also be considered in planning a reclaimed watershed. Cropping is likely to promote infiltration and reduce runoff by repeated manipulation of surface soils. Appropriate grazing management will enhance runoff by managing the vegetative cover, preventing litter accumulation and promoting surface compaction.

Surface storage (other than for beneficial use) will detract from runoff efficiency. Dollhopf and Goering (1982) examined the effects of surface manipulation on runoff from reclaimed lands, and reported that dozer basins were very effective in reducing long-term runoff. Obviously, such measures should not be employed where runoff efficiency is a primary objective.

Wildlife habitat development is frequently cited as a justification for water developments on reclaimed mined lands. (Olson 1981; Hawkes 1978; Parr and Scott 1983). In the semi-arid climate of the Northern Great Plains, sporadic runoff and high evaporation rates result in widely fluctuating water levels in ponds impounding runoff water. Such fluctuations in combination with the need to conserve water by minimizing surface area are likely to prevent establishment of extensive shallows and shoreline habitat diversity. The objective of providing drinking water for livestock and terrestrial wildlife species must take precedence over aquatic habitat development.

Where the pond level is in equilibrium with ground water, as in a final pit impoundment, the opportunities for aquatic habitat development are greater. Bjugstad *et al* (1983) noted that in general, mine ponds have less diverse flora than stockwater ponds due to steeper banks and less extensive shallows. Where a consistent water level can be assured, however, measures to enhance aquatic habitat can be incorporated into the shoreline grading plan.

Regardless of the limitations to aquatic habitat development, any body of water will harbor a community of aquatic species, the nature of which will be a function of site-specific factors. Submergent aquatic plants are likely to become established, as will emergent aquatics where shoreline conditions are favorable. Fulton *et al* (1983) investigated the transplanting of aquatic plant species in mine ponds, with notable success. Quality of water may affect diversity of wetland plant communities (Olson 1981), although in the Northern Great Plains, severe water quality problems have not been experienced.

Aquatic insects will become established quickly in suitable habitats, particularly where the adult forms are terrestrial or highly mobile. Habitat suitability for fish will be limited in small impoundments, although final pit impoundments may be of sufficient depth to prevent freezeout.

Use of reclaimed wetlands by avian and mammalian species will be determined largely by pond size and shoreline habitat. Again, final pit impoundments present the best opportunities to develop habitat for waterfowl, shorebirds, and aquatic mammals.

CONCLUSION

In the semi-arid climate of the Northern Great Plains, establishment of water supplies in reclaimed areas may be vital to the re-establishment of the grazing land use. In addition, terrestrial wildlife species benefit from increased availability of drinking water. The purpose of this paper has been to provide a

basic framework for developing a water replacement plan, recognizing that the design and construction of each new installation will raise new questions, the solutions to which will inevitably advance the state of the art.

The design of reclaimed watersheds for runoff efficiency provides an opportunity which has been largely ignored. Because watershed goals may conflict with revegetation goals to some degree, there is a need to recognize watershed development as a separate post-mining land use category. It is theoretically possible to construct small, high efficiency watersheds surfaced with impermeable spoil materials, to provide a reliable source of water. Although such an approach is not necessarily prohibited by the present legal framework, recognition of watershed values would provide increased flexibility to explore innovative technologies.

There is a similar need to maximize options for impoundment construction. Closed watersheds are discouraged (if not prohibited) by present interpretation of approximate original contour standards. Yet a closed, circular watershed, is likely to provide maximum runoff efficiency with less long-term maintenance than a conventional dam installation. Maximum use of final pit impoundments also is discouraged by current requirements to eliminate highwalls. Goering and Dollhopf (1982) observed that reduction of the highwall in conformance with present regulations would have prevented formation of what has proven to be a successful impoundment. Indeed, final pit impoundments, particularly when constructed to receive water from a large closed watershed of reclaimed spoils, probably present the best opportunity for aquatic habitat establishment.

The art and science of reclaiming mined land in the Northern Great Plains is now more than 15 years old. Although revegetation technology is undergoing continuous refinement, the ability to restore vegetative productivity and utility is no longer a question. The time has come, therefore, to re-examine legally mandated reclamation strategy, and to reshape the regulatory system to promote rather than discourage the use of innovative technologies to meet parallel reclamation objectives. If the full potential of water development on reclaimed lands is to be realized, greater flexibility is essential.

LITERATURE CITED

Bell, H. M., 1973, Rangeland Management for Livestock Production, University of Oklahoma Press, Norman, OK, 303 pp.

Bjurgstad, A. J., et al., 1983, "Prairie Pond Morphometry and Aquatic Plant Zonation - Northern High Plains," Third Biennial Plains Aquatic Research Conference, August 24-25, Bozeman, MT, pp. 101-111.

Bue, I. G., Uhlig, H. G., and Smith, J. D., 1964, "Stock Ponds and Dugouts," Waterfowl Tomorrow, Linduska, J. P., ed., U. S. Dept. of Interior, Washington, D.C., pp. 391-398

Bureau of Land Management, 1964, "Water Development - Range Improvements in Nevada for Wildlife, Livestock and Human Use." 37 pp.

Camenzind, F. J., 1983, "Wildlife and Surface Mining Reclamation," Coal Development: Collected Papers presented in Coal Development Workshops in Grand Junction, Colorado and Casper, Wyoming (BLM), pp. 1187-1284.

Chow, V. T., Ed. 1964, Handbook of Applied Hydrology, McGraw-Hill, New York.

Cluff, C. B., and Frobel, R. K., 1978, "Water Harvesting Catchment and Reservoir Construction Methods," Water Resources Contribution No. 2, Water Resources Research Center, College of Earth Sciences, University of Arizona, Tucson, 44 pp.

Cooley, K.R., 1974, "Evaporation Suppression for Conserving Water Supplies," Proceedings of the Water Harvesting Symposium, Phoenix, AZ, March 26-28, U.S. Dept. of Agriculture, Agricultural Research Service Publication ARS-W-22, pp. 192-200.

Culler, R. C., 1961, "Hydrology of Stock Water Reservoirs in the Upper Cheyenne River Basin," Hydrology of the Upper Cheyenne River Basin, U.S. Geological Survey Water Supply Paper 1531, pp.1-136.

Dedrick, A. R., 1974, "Storage Systems for Harvested Water," Proceedings of the Water Harvesting Symposium, Phoenix, AZ, March 26-28, U.S. Dept. of Agriculture, Agricultural Research Service Publication ARS W-22. pp. 175-191.

Dollhopf, D. J. and Goering, J. D., 1982, "Mined Land Erosion Control with Surface Manipulation," Proceedings 1982 Symposium on Surface Mining, Lexington, KY, Dec. 5-10. pp. 325-328.

Fleming, G., 1971, "Simulation of Water Yield from Devegetated Basins." Journal of the Irrigation and Drainage Division of the ASCE 97(IR2), pp. 244-262.

Fogel, M. M., 1971, "Evaluating the Effects of Water Yield Management," Biological Effects in the Hydrologic Cycle, Monke, E. J., ed, Purdue University, West Lafayette, IN, pp. 303-314.

Frasier, G. W., 1980, "Harvesting Water for Agricultural, Wildlife and Domestic Uses," Journal of Soil and Water Conservation, Vol. 35, No. 3 pp. 125-128.

- Frasier, G. W., and Meyers, C.E., 1983, "Handbook of Water Harvesting," U. S. Dept. of Agriculture, Agricultural Research Service, Agriculture Handbook 600, 45 pp.
- Fulton, B. W., Barker, W. T., and Bjugstad, A. J., 1983, "Rooted Aquatic Plant Revegetation of Strip Mine Impoundments in the Northern Great Plains." Third Biennial Plains Aquatic Research Conference, August 24-25, Bozeman, MT, pp. 113-117.
- Goering, J.D. and Dollhopf, D. J., 1982, "Evaluation of a Mine Pit Water Impoundment in the Semiarid Northern Great Plains." Montana Agricultural Experiment Station Bulletin 748. 62 pp.
- Gwynn, T. A., 1966, "Reclaiming Strip-Mined Land by Establishing Game Management Areas," a Progress Report, Knife River Coal Mining Co., Bismarck, ND
- Haan, C. T., Johnson, N. D., and Brakensick, D. L., 1982. "Hydrologic Modeling of Small Watersheds," ASAE Monograph No. 5, 533 pp.
- Hanson, C.C.; Neff, E. L., and Woolhiser, D. A., 1974, "Hydrologic Aspects of Water Harvesting in the Northern Great Plains." Proceedings of the Water Harvesting Symposium, Phoenix AZ, March 26-28, U.S.D.A. Agricultural Research Service Publication ARS-W-22, pp. 129-140.
- Harju, J. H., 1980, "Reclamation for Wildlife - The Wyoming Viewpoint," Proceedings, Adequate Reclamation of Mined Lands? - Symposium, Billings, Montana, March 26-27.
- Hawkes, C. C., 1978, "Aquatic Habitat of Coal and Bentonite Strip Mine Ponds in the Northern Great Plains." Ecology and Coal Resources Development, M.K. Wali, ed., Pergamon Press, New York, pp. 609-614
- Heady, H. F., 1975, Rangeland Management, McGraw-Hill, New York, NY, 435 pp.
- Jackson, M. R., 1984, "Wyoming Reclamation and Wildlife Impact Mitigation," Proceedings of the Third Biennial Symposium on Surface Coal Mine Reclamation on the Great Plains. Billings, Montana, March 19-21, pp. 143-153.
- Linsley, R. K., Kobler, M. A., and Paulhus, J. C. H., 1949, Applied Hydrology, McGraw-Hill, New York, 689 pp.
- Myers, L.E., 1974, "Water Harvesting - 2000 B.C. to 1974 A.D." Proceedings of the Water Harvesting Symposium, Phoenix, AZ, March 26-28, U.S. Dept. of Agriculture, Agricultural Research Service Publication ARS-W-22, pp. 1-7.
- Neff, E.C. and Wight, J. R., 1983, "Soil Vegetation - Hydrology Studies Volume 1," Research Results. Summary, Discussion and Recommendations, U.S.D.A. Agricultural Research Service Publication ARR-W-28, 55 pp.
- Olsen, R. A., 1981, "Wetland Vegetation, Environmental Factors, and their Interaction in Strip Mine Ponds, Stockdams and Natural Wetlands." U.S. Dept. of Agriculture, Forest Service, General Technical Report RM-85, 19 pp.
- Parr, D. E. and Scott, M.D., 1983, "Improving Aquatic Habitat Through Coal Surface Mining in the Plains," Proceedings of the Third Plains Aquatic Research Conference, Bozeman, MT, August 24-25, pp. 137-152.
- Rosso, W. A., 1979, "Water: Resource or Liability in Surface Mining," Proceedings of the Symposium on Surface Coal Mining and Reclamation, Louisville, KY, Oct. 23-25, pp. 99-102.
- Rumble, M. A., "Quality of Water for Livestock in Man-made Impoundments in the Northern High Plains" Unpublished Manuscript. U.S. Dept. of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Rapid City, SD, 13 pp.
- Smith, A. D., 1954, "How Much Water does a Deer Drink?" Utah Fish and Game Bulletin 19(9):1,8.
- Soil Conservation Service, 1972, "Hydrology Section 4" SCS National Engineering Handbook, U.S. Dept. of Agriculture.
- Stoddart, C. A., Smith, A.D., and Box, T. W., 1955, Range Management, McGraw-Hill, New York, 532 pp.
- Vallentine, J. F., 1971, Range Development and Improvements, Brigham Young University Press, Provo, UT, 545 pp.
- Van Voast, W. A., Hedges, R. G. and McDermott, J. J., 1978, "Strip Coal Mining and Mined-Land Reclamation in the Hydrologic System, Southeastern Montana," Old West Regional Commission, Billings, MT 121 pp.
- Walton, W.C., 1972, Groundwater Resource Evaluation, McGraw-Hill, New York, 664 pp.
- Wollenhaupt, N. D. and Richardson, J.D., 1982, "The Role of Topography in Revegetation of Disturbed Lands," Proceedings of the Symposium on Surface Coal Mining and Reclamation in the Northern Great Plains, Billings, MT, March 8-9, pp C-2-1 to C-2-11.
- Yoakum, J., 1984, "Pronghorn Habitat Requirements and Reclamation," Proceedings of the Third Biennial Symposium on Surface Coal Mine Reclamation on the Great Plains, Billings, Montana, March 19-21, pp. 148-154.

