Chapter 8

WETLAND CREATION AND RESTORATION

SOUTH DAKOTA DRAINAGE MANUAL

October 2011

Table of Contents

Section **Page**

Table of Contents
(Continued)

Section **Page**

Table of Contents
(Continued)

List of Figures

Chapter 8
WETLAND CREATION AND RESTORATION

8.1 INTRODUCTION

8.1.1 General

Wetlands became the focus of national attention in 1977 with the issuance of Executive Order 11990, which required Federal agencies to minimize the destruction, loss or degradation of wetlands. This Federal policy is accomplished in the environmental review process and through procedures such as USACE's Section 404 permit regulations. Other Federal regulations include NEPA, *Endangered Species Act* and the *Clean Water Act*, which includes the 404 permit. In addition, there may be applicable State or local requirements; see Chapter 2 "Legal Aspects."

The National Wetland Inventory (NWI) is a geospatial database maintained by the United States Fish and Wildlife Service. This database contains information on the location, type and function of all wetlands found in the United States. Data from the NWI is used to determine if a particular project will require wetland mitigation. See Reference (1) for information specifically on wetlands in the State of South Dakota.

If a wetland area cannot be avoided, this Chapter is presented to give the highway hydraulic engineer some familiarity and guidance on the restoration and creation of wetlands. It is not intended to be a definitive thesis on wetlands hydrology. For a more complete discussion of the subject, refer to References (2) and (3).

8.1.2 The Functions of Wetlands

One of the important aspects of wetlands is the variety of functions that they perform. In the creation/restoration process, the determination of the functions that the proposed project is intended to accomplish is one of the most important design considerations. Natural wetlands perform a number of functions. Many functions are based on subtle relationships, which may have occurred from as few as three years to thousands of years to develop. Some of the functions performed by wetlands are listed below:

1. Plant and Animal Habitat. "*Wetlands represent a very small fraction of our total land area, but they harbor an unusually large percentage of our wildlife*" (Reference (4), pp. 15 and 16).

2. Food Chain Support. Wetlands have the capacity to accumulate nutrients.

3. Flood Storage. Many wetlands are natural flood detention areas.

4. Sediment and Pollutant Trapping. Because of the slow water velocities in wetlands, most sediment flowing into the wetlands will be trapped.

5. Shoreline Protection. Wetland vegetation along shorelines of lakes and rivers provides soil stabilization by absorbing and dissipating the energy of waves and currents and by binding the soil.

6. Groundwater Recharge. Most wetlands have limited value as groundwater recharge areas.

7. Groundwater Discharge. Wetlands that intersect the watertable can serve as groundwater discharge points if the piezometric surface (head) is sufficient.

8. Biogeochemical Cycling. Two examples of this process are the accumulation of various forms of carbon in peat bogs and the reaction of sulfur with other elements in wetlands and its release as gaseous and liquid compounds.

9. Recreation, Education, Heritage. Wetlands are used for hunting, fishing, birding and canoeing. The rich habitat of wetlands demonstrates the dynamics of ecological systems.

The ability to restore or create wetland functions is dependent on how much is known scientifically about the functions, the ease and cost of construction and the varying probability that construction can cause nature to duplicate certain functions. A restored wetland, in many cases, can perform most of the functions that it did in its pre-impact state. Created wetlands may be less successful in filling the functions of natural wetlands in the short term. In the long term, the wetland functions should be more established. As examples:

- Flood storage is relatively easy to duplicate. It primarily depends on topography, which is easy to construct.
- Groundwater recharge and discharge functions are more difficult to assess and construct.
- Infiltration, which is necessary for groundwater recharge, is difficult to construct. Sandy soils may become impermeable over time due to deposits of organic material.

8.1.3 Role of Specialists

8.1.3.1 Environmental Office

The lead role in creation/restoration projects is taken by the Environmental Office or Wetland Biologist.

The Department requires avoidance of all wetland impacts or, where avoidance is not practical, minimization to the greatest extent practical. Special emphasis is placed on avoiding impacts to high-quality wetlands including those wetlands with known or potential endangered species support functions.

When the objectives of a transportation project cannot be met without adverse impacts to wetlands, wetland mitigation involves the preparation of a wetland mitigation plan detailing how lost wetland functions will be compensated. Subsequently, the Environmental Office submits the wetland mitigation plans to one or more regulatory agencies, typically the US Army Corps of Engineers, Omaha District; USFWS Pierre Ecological Field Services Office; South Dakota Game, Fish & Parks; and South Dakota Department of Environment and Natural Resources, for their review and permit approval. Even where the impacts are so small as to fall below regulatory thresholds, SDDOT follows a "no-net-loss" directive requiring compensatory mitigation for any wetland loss.

The SDDOT Environmental Office maintains a listing of wetland mitigation banking activities. This system reflects project agreements reached with regulatory agencies concerning wetland impacts and restoration.

8.1.3.2 Hydrologist

The responsibility of the hydrologist (or geohydrologist) in the creation/restoration process is to ensure that the proper hydrology is supplied to the project. *"Hydrology is the most important variable in wetland design. If the proper hydrologic conditions are developed; the chemical and biological conditions will respond accordingly"* (Reference (5), p. 592). The ultimate success of any wetland project depends on establishing or restoring and maintaining the appropriate hydrology to support the wetland. Without the proper hydrology, the wetland project may fail.

It should be noted that hydrology is not the only important variable in the wetland creation/restoration process. Wetlands are, by definition, vegetated areas that use water at a high consumption rate. All the variables necessary for vegetation should be present. Another major variable is the soil substrate. It should be present to supply the necessary nutrients and rooting medium.

8.1.3.3 Highway Hydraulic Engineer

Although wetland hydrology is not a primary responsibility for highway hydraulic engineers, they may be required to work in this discipline with increasing frequency because wetland mitigation needs have increased in highway construction. Their responsibility will be to fill the role of the hydrologist in the wetland creation/restoration process. Because highway hydraulic engineers are usually concerned with providing for the hydrologic and hydraulic design needs for a highway construction site, they should become familiar with the biological aspects of wetland creation/restoration to successfully fulfill their role in the process.

Groundwater is often an important aspect of wetland creation/restoration projects. Most highway hydraulic engineers are surface water specialists and do not have extensive experience in groundwater. This Chapter is primarily concerned with the surface water aspects of wetland creation/restoration and discusses the groundwater aspects only as necessary. If groundwater is important to a project, it is recommended that an individual qualified in groundwater be engaged to address that aspect of the project.

8.1.4 Wetland Hydrology

Wetland hydrology may be roughly defined as the flow of water into, through and out of a wetland and the characteristics of this flow. The characteristics include the depth, duration, velocity, sediment load, chemistry and temperature. The sensitivity of wetlands to hydrology is evident in the water depth tolerance for wetland vegetation. For some species, the range of depth tolerance is in the order of 1 in to 4 in. A small change in hydrologic conditions will result in a major change in the species richness, diversity and abundance of the biota. An abrupt and major change in the living matter in a wetland can result from a relatively minor change in hydrology. Therefore, the hydrology of a proposed wetland restoration or creation site should be thoroughly evaluated and very carefully designed.

The hydrology determines the availability of water and the depth, velocity, chemistry and soil conditions. The water inflow into wetlands is the main source of nutrients for the wetland fauna and flora, and the outflow often removes biota (i.e., any living material) and non-biological material from the wetlands. "*In the short-term, hydrology determines vegetation, fauna and most of the wetland functions. In the longer term, hydrology determines, through erosion and deposition, the shape, size, depth and even the location of a wetland. This, in turn, determines vegetation, fauna and wetland functions*" (Reference (6), p. 4). Hydrology controls the types of plants that grow in an area. Fewer and fewer types of plants out of thousands can grow as saturation conditions increase. Although the variety of plants that can grow in a wetland decreases as the depth and duration of flooding increases, the wetland's overall production of biota may not necessarily follow this trend. Though diversity may decrease, the total volume of plants and organisms supported by the wetland, in some cases, may be greater for the deeper, more frequently flooded areas.

The role of long-term hydrologic events such as flooding and long-term fluctuation in the water level and their effects on plant life is not known. The hydrologic needs and requirements of various plants and animals including the seasonal variation in wet and dry periods need to be studied. A recent study indicates that variation in plant community may be explained by one-day to ten-day duration flood frequencies. The six-day duration flood frequency has been recommended as a reasonable measure (Reference (7)).

Some useful references for freshwater wetland creation and wetland hydrology that are not specifically cited within this Chapter are References (8) through (15).

8.2 WETLANDS AND WETLAND MITIGATION PROJECTS

The USACE and the USEPA have defined "jurisdictional" wetlands as:

> *Those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas*. (Reference (16)).

Wetlands will have the following general diagnostic environmental characteristics:

- The prevalent vegetation consists of plants that are adapted to the conditions indicated above and have the ability to grow, reproduce and/or persist in anaerobic soil conditions.
- The soils are hydric or have characteristics of soils developed under reducing conditions.
- The hydrology is such that the area is permanently or periodically inundated up to 6.5 ft deep, or the soils are saturated to the surface sometime during the growing period of the predominant vegetation.

Wetlands are an ecotone or transition zone between dry land and deep water (i.e., water 6.5 ft or more deep). This boundary shifts back and forth due to changing climatic conditions. Climatic conditions gradually change between wet and dry over long periods of time. This causes a gradual change in soil wetness affecting vegetation and blurring the wetland boundary. Only properly trained wetland specialists are qualified to identify wetlands.

Wetland mitigation projects involve creation or restoration of wetlands. A wetland creation project is the construction of a wetland where none existed before. This type of project is difficult to construct and has less chances of success than a restoration project because it requires a successful change in hydrology. Restoration projects involve repairing and restoring a damaged or destroyed wetland. Success is more likely for this type of project.

Reference (17) presents guidelines for restoring and creating wetlands for highway projects specifically in South Dakota. The publication presents:

- biological, hydrological and soil factors that define a wetland;
- need for wetland mitigation and regulations;
- services and functions a wetland will provide society; and

- design features for consideration of hydraulic engineers:
  + restored wetlands made by plugging a ditch or breaking drainage tile,
  + embankment wetlands made by building a dam in a watercourse, and
  + excavated wetlands made by excavating a depression in a level area.

8.3 WETLAND HYDROLOGIC PRINCIPLES

8.3.1 Introduction

Wetland areas may experience periods of being wet and dry during the year. One wet period should be during the growing season of the vegetation. The wet period may involve inundation or soil saturation. It should persist for sufficient time to cause the vegetation to be predominantly hydrophytic (water tolerant). There can be some non-hydrophytic plants in a wetland but they should not be predominant.

The seasonal variation in wet and dry periods in a wetland is called hydroperiod. The hydroperiod is the result of the summation of all the inflows and outflows in a wetland. It is influenced by topography, geology, climate and the adjacent water bodies. The results are wet and dry periods that vary from year to year. It is this pattern that determines the characteristics of the wetland. The dry periods are called drawdown. The role of drawdown in plant zonation and succession is well understood. It is an important tool of wetland management and should be an important part of wetlands planning considerations. In wetland restoration projects, drawdown is enhanced by gently sloping bottoms. If drawdown is not planned for in wetland development, the result will likely be an open body of water rather than wetlands.

There may be some long-term cycles in the amount of water available for the wetlands. Prairie potholes have a wet and dry cycle that ranges from 10 to 20 years.

In a simplified view of natural wetlands, the supply of water overwhelms the outflow capacity of the area. The resulting oversupply of water is stored and released slowly over time. If the water is released too quickly, a wetland will not form. The storage may be in the form of surface water impoundment or in an elevated groundwater table. In some cases, there may be no outflow from the wetlands such as prairie potholes. Some wetlands are formed when the watertable is at or near the surface.

The basic procedure to restore or create a wetland area in this simplified model is to construct the conditions that will provide the necessary excess water. There are several approaches to provide the excess water. One approach, particularly where the water supply is limited, is to create an impoundment. To do this, the soils should be impervious and some type of spillway control structure should be constructed. Sufficient control should be built into the spillway so that the appropriate wet and dry periods will result. The critical factor is a sufficient water supply to make the system work. Another approach is to have a sufficient supply of water to raise the groundwater table to the required levels to maintain a wetland area.

8.3.2 The Water Budget

The primary procedure that is used to determine the hydroperiod for a proposed wetland creation/restoration project is the development of a water budget. The water budget is a routing procedure that is developed on a monthly basis over a period of a year. It is the summation of the water inputs and outflows in a wetland area. Expressed in terms of depth of water in the wetland basin in feet, it measures the volume of water stored in the wetland. The inflows to the wetlands are precipitation, surface water flow and groundwater flow. The outflows are evaporation and transpiration (terms sometimes combined as evapotranspiration), surface flow and groundwater flow. One or more of the types of inflow or outflow may not be present in a particular wetland. A successful design can be accomplished if there is a reliable water source available. The source can be a permanent stream, the runoff from a large watershed, a spring or a well-understood groundwater table. To be assured that the proper water levels can be maintained under extreme conditions, a water budget should be developed for the project site for the wettest year of record, the driest year and a normal precipitation year. The purpose in evaluating these three conditions is to provide the wetland specialist with the range of hydrologic conditions that the wetland area will experience. This will allow the wetland specialist to evaluate the chances for success of the wetlands and to determine the need for adjustment in the design for the hydrology of the wetlands. The water budget is explained in Section 8.11.

8.3.3 Wetland Soils

One of the important aspects of wetlands is that the soils are hydric. Hydric soils are saturated long enough in the growing season to support wetlands or hydrophytic vegetation. The soils may be organic or mineral. *"Organic soils are commonly known as peat or muck. Organic soils (Histosols) develop under conditions of nearly continuous saturation and/or inundation. All organic soils are hydric soils, except Folists, which are freely drained soils occurring on dry slopes where excess litter accumulates over bedrock"* (Reference (18)). The mineral soils may range from sands to clays.

Hydric soils are anoxic, or they lack or have low levels of oxygen. The primary difference from non-hydric soils is that water fills the voids between soil particles, greatly inhibiting the replacement of atmospheric oxygen in the soil. As a result, there is only a thin layer 0.04 in to 0.20 in thick that has adequate oxygen to maintain aerobic/oxidation conditions. Almost everything below this layer is anaerobic. Shortly after the soil is flooded, the microbes will use up the available oxygen, and the soil will become anaerobic. Under anaerobic conditions, decomposition is greatly reduced. *"In summary, the loss of soil oxygen creates difficult environmental conditions for living organisms and unusual chemical conditions that, in turn, result in the unique attributes of wetland soils that contribute to their functional values"* (Reference (4), p. 33). For a more complete discussion of hydric soils; see Reference (4) and Reference (18).

Hydric soils occur when they have been subject to hundreds of years of reducing conditions from periodic saturation. Hydric soils from an impacted wetland should be stockpiled or saved for placement into another wetland mitigation area. They should be placed in a created wetland before planting or flooding. Experience dictates that wetland creation is not successful without the placement of hydric soils.

8.4 CRITICAL HYDROLOGIC VARIABLES OF WETLANDS

The two hydrologic variables that are critical for making management decisions for wetland projects are discussed below. The following hydrologic variables may have to be considered as appropriate:

- velocity of water;
- wave action;
- areas subject to ice;
- effects of variations in water sources;
- dissolved and suspended materials in water, turbidity and temperature;
- size, shape and depth of wetlands;
- wetland vegetation;
- wetland soils; and
- wetland organisms.

8.4.1 Water Sources and Outflow from Wetlands

The source of water to wetlands will influence the characteristics of the wetlands. Streams or rivers supply water with relatively high energy and large sediment and nutrient loads. The high energy can damage some features of wetlands. Although the sediment can choke out or bury some vegetation and animal life, nutrients carried by the sediments can also enrich the wetlands. Sheet flow can also bring sediment, nutrients and pollutants to the wetlands. The sediment loads from sheet flow will be relatively minor compared to the loads from a river. The pollutants can be from agricultural runoff containing fertilizers, insecticides, herbicides and animal waste products. In addition, pollutants can come from urban and industrial runoff. Groundwater-supplied wetlands will have relatively clean and cool water.

The outflow from the wetlands affects the nutrient balance of wetlands. If the outflow is through a surface flow or a stream, some of the dissolved and suspended material will be transported out of the wetland. If the primary outflow is through evapotranspiration, the wetland will be a sink for sediment and nutrients. Wetlands that discharge into groundwater will serve as groundwater recharge areas.

8.4.2 Depth of Water in Impounded or Inundated Wetlands

In impounded or inundated wetlands, the depth of water determines the characteristics of the wetlands. Plant species are very sensitive to inundation depths and periods. Both aquatic and non-aquatic animals in wetlands are largely dependent on water depths for habitat.

Depth of water plays a part in both definitional and legal points of view. As indicated in Section 8.2, wetlands are defined as having a depth of water less than 6.5 ft.

The varying depth during alternating wet and dry periods or hydroperiod determines the types of plant life that inhabit a wetland. Forested wetlands, in particular, are very sensitive to depth and hydroperiod. Plant life is also sensitive to periodic flooding, including extremely rare, high-magnitude flooding events. In natural wetlands, the balance due to hydroperiod and depth is achieved over long periods of time but, in created wetlands, this balance may be difficult to duplicate. Current understanding of the impacts of floods, particularly rare, high-magnitude floods on hydroperiod and wetland vegetation, is limited. This is especially true for forested wetlands. Because of this lack of understanding, the long-term success for created wetlands is less certain.

The mechanism that is used to vary depth in a created wetland is topography. Constructed wetlands should have a very gradually sloping bottom or hummock and hollow topography to make sure that the appropriate depths for desired vegetation are achieved.

8.5 GENERAL PRINCIPLES FOR WETLAND DESIGN

In their book, *Wetlands*, Mitsch and Gosselink (Reference (5)) provide a list of principles for design and construction of wetlands. These are summarized below:

- The wetland system should be designed for minimum maintenance. The hydrology and plant life should be self-controlling and self-sustaining over the long term. The system should be designed so that it uses natural energies. The natural energies of floods circulate nutrients throughout the wetlands.
- Design the system to operate successfully within the natural climate and landscape. Floods and droughts should not be feared for they are a part of nature.
- The system should be designed with multiple goals; however, there should be one main objective with several secondary objectives.
- Design the wetland as an ecotone, which is a transition zone between dry land and deep water. A buffer strip may be needed around the wetland, but the wetland itself functions as a buffer between the dry land and the deep-water areas.
- The wetland system should be given time to become established. Short-term success or failure may not reflect the true success of the system.
- The wetland system should be designed for function and not form. If a particular planting fails, but the desired function succeeds, the objectives are met. Plant diseases and invasion by exotic or nuisance species may indicate other stresses and may indicate false expectations and not ecosystem failure.
- The wetlands should reflect the general topography of the area and not regular geometric shapes.

8.6 WETLAND TYPES FOR DESIGN MODELS

South Dakota wetlands consist of four different types based on how they fit the terrain and how the water is supplied. There may be some overlap, but these four types are presented as a framework for design concepts only. In Section 8.7, more specific design models are presented:

1. Surface Water Depression. The surface water depression wetlands are depressions in the ground with a lining of impermeable soils. Normally, they do not intersect the watertable. This type of wetlands will require a sufficient drainage area to develop necessary surface water and precipitation for water supplies.

2. Surface Water Slope. Surface water slope wetlands are located adjacent to another body of water, a stream, lake or pond. The water supply is furnished by the adjacent water body. The hydroperiod of this type of wetlands is directly related to the rise and fall of the parent water body. Surface water slope wetlands are relatively easy to construct. The effects of wave action and sedimentation should be considered.

3. Groundwater Depression. The groundwater depression wetlands are similar to the surface water depression wetlands, except that they do intersect the watertable. They will usually not have an overland outlet. Water supplies from the groundwater table may be sufficient. Dependency on groundwater for water supply should be approached with caution. A sufficient investigation and verification of the reliability of the level of the watertable should be undertaken by a groundwater specialist to verify the adequacy of the supply before dependence is placed on the groundwater supply. The water level will reflect the groundwater table and will rise and fall in a cyclic manner with the watertable.

4. Groundwater Slope. The groundwater slope wetlands are constructed along a slope that intersects a permanent or semi-permanent seep or spring. Surface water and precipitation can be a substantial part of the water supply for this type of wetlands. Groundwater slope wetlands are more likely to have successful construction efforts than groundwater depression wetlands.

8.7 MODELS FOR WETLAND CONSTRUCTION

The basic models for wetland construction depend on water supplies from precipitation, surface water, stream flow, lakes, reservoirs and groundwater. In this terminology, "model" refers to the particular method of supplying water to the wetlands. These water sources may be used singly or in combination depending on how the wetlands fit the topography. The outflows will be through two designer-controlled methods (a spillway structure or surface channels) and through two natural control methods (groundwater infiltration and geographically controlled evapotranspiration). The four model types that are most likely to be constructed by SDDOT are discussed below. The other possible models are listed below and are discussed in Reference (2):

- groundwater interception,
- shared water supply,
- aquatic bed,
- lakeshore,
- island wetlands, and
- riparian rehabilitation.

8.7.1 Inline Stream Flow Model

There are two ways to construct wetlands using inline stream flow. One is to follow nature's example and emulate the beaver by constructing a dam or control structure across the stream channel. The other is to excavate an area adjacent to the stream so that it can be periodically flooded by high water and to construct an erosion control weir across the stream. Special accommodation may be required for fish passage. The inline method is more appropriate for areas near the headwaters of the stream. It works well for ephemeral streams or for perennial streams that have low flood discharges and low sediment transport. Placing a control structure at the upstream end of a highway culvert is an inexpensive way to construct an inline wetland. However, before any control structure is placed at the upstream end of a culvert, it should be reviewed by a hydraulic engineer to determine if there will be any detrimental effect on the culvert's hydraulic performance.

The main water source for the inline model is the stream flow. Flow rates can be determined using hydrograph methods or, if the stream has a USGS gage, gaged data can be used for the flow data (see Section 7.8). Flow depths can be approximated by Manning's equation. A more accurate method is to use one of the step-backwater models such as HEC-RAS to compute flow profiles (see Section 18.2.1).

The dam structure should be designed using normal dam design principles, should be relatively low, and should have 10H:1V side slopes. This extremely flat slope will help protect the dam from damage by burrowing animals.

The main usefulness for the inline model is that it can support a wetland where the soils are relatively permeable. In such cases, the wetlands can be a recharge area. The primary disadvantage is that the wetlands may be constructed in a high-energy area of the stream. This will allow for sediment deposition and erosion in the wetlands. Scour problems along ground-level access roads may also be a problem in high-energy areas of a stream or floodplain.

8.7.2 Offline Stream Flow Model

An offline stream flow model works by diverting water from a stream channel during high-flow periods or by the construction of a weir in the channel that can be used to divert water during low-flow periods. As indicated above, special accommodations may be required for fish passage. In some cases, frequent flooding such as the annual flood can be used to recharge the wetlands. The offline stream flow model is useful when the stream has a high sediment load, is too flashy, or has high steep banks that are not suitable to inline construction techniques.

Discharge data and water profile data should be determined similarly as in the inflow model process. If the stream has large flow fluctuations and no gage data is available, biologic and geomorphic conditions in the area can serve as guides in establishing wetland elevations. The elevation of existing wetlands and natural levees that control the water retention are essential design information. High-water marks are also important indicators.

The water level in the offline wetland model should be controlled by a weir at the outlet of the wetlands or by the elevation and capacity of the outfall channel. It is important to build flexibility in controlling this elevation through an adjustable weir control. This, as discussed later, will allow for corrections or adjustments in the water level in the wetland.

If sediment control is not a functional goal, then one of the most important considerations in the offline model is to have some sediment control upstream from the wetlands. This is particularly true because the recharge is usually during high-flow events when the stream is carrying its largest sediment load. The majority of the sediment should be trapped before it reaches the wetland area. However, some of the finer materials may provide nutrients to the vegetation in the wetlands.

Some of the advantages of the offline model are:

- the stream will furnish an adequate water supply,
- the monetary value of floodplain land is relatively low,
- a minimum of excavation is needed,
- the model will work with permeable soils, and
- the wetland can be a link with other wetland habitats.

The main disadvantage is that there may be difficulties in obtaining permits for the channel modifications.

8.7.3 Spring/Seepage Flow Model

Wetlands developed using this model fall into the category of groundwater slope wetlands. They are constructed just down slope from a spring or from a point where the groundwater table intersects the surface. The wetlands are constructed by excavating a benched area and building a dam to contain the water.

The flow rates from the groundwater source should be known or estimated. Flow rates may be determined by gaging. A V-notch weir may be needed for accurate gaging. The reliability of the source should be determined by examining historical records, by interviews with long-time local residents and by judging changes in vegetation in the area downstream of the seep. The groundwater can be supplemented with surface water from the uphill area.

It is important to determine if activities in the source area of the aquifer will affect the groundwater flow. Activities that may have an impact are:

- urbanization,
- agriculture,
- forestry,
- irrigation, and
- groundwater development.

The dam structure should be designed using normal dam design principles, should be relatively low, and should have 10H:1V side slopes. This extremely flat slope will help protect the dam from damage by burrowing animals.

The advantages with this type of model are that it is relatively easy and inexpensive to construct and that it depends on a relatively reliable water source. The disadvantage is that a water control structure should be constructed that might fail and that a seep habitat will have to be destroyed.

8.7.4 Surface Water Model

This model is constructed by diverting surface water flow into an impounded area. Flow rates can be readily computed based on rainfall records and a synthetic hydrograph. The watershed should produce reliable runoff. The impounded area should have impermeable soils or have a sufficient water supply to maintain the required water levels. A spillway structure will be required with sufficient capacity to allow the passage of excess water so that vegetation will not be damaged.

There is a growing body of literature on "moist soil management" for waterfowl habitat. Moist soil management relies on moist soil conditions followed by drawdown periods. The soil moisture is then replenished by flooding. USFWS has an introductory manual for these techniques. See Reference (19). The Ducks Unlimited website provides conservation practices, with specific information related to South Dakota.

The main advantage with this method is that it is easily and inexpensively constructed. The main disadvantage is that it cannot be constructed in areas with permeable soils, unless there is sufficient water supply to maintain the required water levels or unless an impermeable liner is used.

8.8 WETLAND CREATION/RESTORATION MANAGEMENT

"The success of a project depends upon the ease with which the hydrology can be determined and established, the availability of appropriate seeds and plant stocks, the rate of growth of species, the water level manipulation potential built into the project and other factors. To date, the least success has been achieved for wetlands for which it is very difficult to restore or create the proper hydrology" (Reference (20)).

The success rate with restoration of wetlands has been relatively high. Long-term success of a project depends on monitoring, managing and protecting the wetlands. Long-term success can also be affected by land-use changes in the surrounding area, which will usually be outside project control. Projects should be designed as self-sustaining, unless another agency is willing to take the responsibility for long-term maintenance. However, the ultimate goal of all projects is that they should be self-sustaining. Common management tools needed are:

- make mid-course corrections including replanting, regrading and adjustments to water level;
- establish barriers, buffers and sediment traps to protect the wetlands from excessive sediment, nutrients, pesticides and other impacts from adjacent lands that can include agricultural activities and urbanization;
- establish barriers and fences to protect the wetlands from foot traffic, off-road vehicular traffic and livestock;
- control invading undesirable plant life by burning, herbicides or mechanical removal;
- remove accumulated sediment by dredging or other means; and
- provide supplemental watering during early establishment period.

8.9 WETLAND CREATION/RESTORATION PROJECT TEAM

The development of a wetland creation/restoration project should be accomplished by a multi-disciplinary team. Representatives of the disciplines that may be on the team are:

- wetland specialist/Environmental Office,
- wetland biologist,
- hydrologist/groundwater hydrologist,
- hydraulic engineer,
- geotechnical engineer/geologist,
- civil engineer, and
- landscape architect.

8.10 WETLAND CREATION/RESTORATION PROJECT PROCESS

8.10.1 Basic Process

The wetland creation/restoration process should follow a logical process. The Steps in this process are:

- Assess the wetland to be replaced or mitigated to determine the functions and values to be replaced. The assessment should include an inventory of the plants and organisms and an evaluation of the hydrology of the wetland site.
- Based on the assessment, establish a baseline of wetland characteristics from which a set of objectives for the proposed creation/restoration project can be developed.
- Establish goals and success criteria for the proposed project based on the objectives and the site analysis.
- Evaluate potential project sites.
- Select project site.
- Depending on the size and complexity of the mitigation required, a detailed evaluation of the project site will include a topographical survey, geotechnical survey, hydrologic evaluation, plant survey and fish and wildlife evaluation.
- Design the project to include the hydraulic design with the development of a water budget, geotechnical design, design for restoration of wetland plants and wildlife, habitat features, a construction sequencing plan and maintenance.
- Construction of the project should include quality control and in-course corrections.
- Provide monitoring and adjustments.

The remainder of Section 8.10 elaborates on this basic process.

8.10.2 Evaluation of Existing Wetlands

The first five Steps in the wetland creation/restoration process are interrelated and constitute the planning process for the project. The identification and evaluation of a reference wetland is used to establish a baseline by which the project mitigation site can be measured. The reference wetland allows an understanding of the character of the wetland and of its functional values. The success of the creation/restoration project is measured by comparing the finished mitigation site with the reference wetland. An important part of the evaluation is to answer the following questions (Reference (21), p. 328):

- Is the wetland being created to replace habitat? What type? Is a similar habitat feasible? What species (plant and animal) are desired?

- Is the wetland expected to perform specific functions, such as flood control, wastewater treatment and sediment trapping? What features are required to perform these functions (area, flow rate, etc.)?

The non-biological items that should be evaluated are the topography, the hydrology and the geology. The evaluation of the general topography of the wetlands should include the size and shape of the wetland and the detailed ground contours of the wetland area. The hydrology should include developing and understanding both the groundwater and surface water hydrology of the wetland. In the groundwater investigation, the following areas should be investigated:

- the geologic history of the site including an understanding of the existing topographic and hydrologic setting; and

- an investigation of the different strata that underlies the wetland site, including a determination of their characteristics such as permeability and the groundwater table using watertable observation wells.

The surface water hydrology evaluation should include the source or supply of water, the types of outflow mechanisms and the quality of the water supply. The interaction of the site hydrology with the surrounding area should be determined. Does the wetland serve as a flood storage area and does it act as a sediment trap? A water budget should be developed, including the groundwater and the surface water.

The drainage area of the watershed, the nature of the watershed and the land use of the surrounding area should be determined. An evaluation of the interactions between the wetlands and the surrounding area should be made to develop an understanding of the interrelationships that exist and what role they play in the functions of the wetland.

The biological element of the wetlands should be evaluated. Depending on size and location of the wetlands, inventories or counts of the plant and animal life may be taken. Threatened or endangered species should be identified. The functions of the wetlands should be identified and quantified. Because wetlands are not independent of their surroundings, the interaction of the wetland with the surrounding area should be investigated.

8.10.3 Establish Goals and Success Criteria

Without specific and realistic goals and objectives, there is no way to evaluate the success of the project. The goals should be based on the evaluation of the wetland that is being replaced. The design goals are project specific and should be developed by the project team based on the needs of the desired functions of the wetland. All members of the wetland project development team should have input into this process. Considerations for the goals and design criteria should include hydrology, topography, geology, plant species and water control devices. This means that the goal selection, design criteria and the design require a broad approach, considering all of these factors. In the goal-setting process, it is important to understand that only a few of the natural functions of a wetland can be created.

8.10.3.1 Success Criteria

As part of the goal-setting process, specific success criteria matched to functions should be defined. Otherwise, there is no method to determine whether the constructed wetlands are successful. The success criteria should identify specific plant survival, growth rates and habitat conversion based on a realistic time scale. The goals allow the process to be measured and experience to be gained. The success criteria also give a basis for making midcourse corrections. The entire process should be measured against the baseline established in the evaluation of the original wetland. The success depends on how well the original evaluation was accomplished and the practicality of the original goals.

8.10.3.2 Timetable for Monitoring

One of the key elements of the goal-setting process is to establish a timetable for monitoring the project. The timetable should determine when the project will meet various stages of development and when it should successfully meet the goals. Enough flexibility should be designed into the hydraulic controls for the wetlands so that needed adjustments in water depth can be made if the vegetation is not developing as it should. Other adjustments may include removal of nuisance species or replanting. Monitoring should begin when the planting has been accomplished and should continue until the permit requirements of the regulatory agencies have been met.

8.10.3.3 Hydrology Goals and Criteria

The primary goal should be to establish the long-term hydrologic conditions that will support the desired plant community. The hydrology should be designed as a stand-alone system, requiring little or no maintenance once it has become established. Other very important functional goals may be stormwater retention, water quality improvement, sediment control, wastewater treatment, fish and wildlife habitat creation and recreational use. Flood routing analysis is essential in assessing the significance of flood storage benefits of wetlands. Many wetlands do not provide significant flood storage benefits.

Wetland vegetation and wildlife have specific hydrologic requirements to survive and flourish. These requirements are generally for depth and seasonal timing of inundation. Velocity and circulation requirements may be needed to enhance nutrient cycling. The biologist should define these requirements for the hydrologist based on the needs of the specific species of plants and animals that are identified in the goals for the wetlands. These requirements are the hydrologic goals for the wetland project. Once the goals have been furnished, the next step for the hydrologist is to define the hydrologic design criteria needed to achieve the project goals. The hydrologic design criteria should provide for some control flexibility so that adjustments in water level can be made. This is because hydrologic needs for vegetation are not completely understood and hydrology for a watershed cannot be determined to a sufficient level of accuracy to fully realize these goals.

8.10.4 Selection of Project Site

The site selection process is probably the most difficult part of the creation/restoration process. Alternative sites should meet the goals of the project and satisfy the requirements of the regulatory agencies. The most important criterion for site selection is that the required hydrology can be established. Soils and geology characteristics are critical factors in determining whether this can be accomplished. Other questions that should be addressed are:

- Will the site be large enough to meet the mitigation requirements?
- Is there sufficient room for a buffer strip to protect wildlife?
- Can the property be acquired?
- Is the cost within the project budget?
- Can the site be protected from detrimental human intrusion?
- Is the replacement wetland site in close proximity to, within the same drainage basin, or greatly removed from the impacted wetland?
- Are there water rights considerations?
- Will the site create health or safety hazards to the public?

These are among the many questions that should be addressed before the final site selection can be made.

Potential sites should be identified in the project area. Preferred sites should be wetlands that have been destroyed or damaged. Creation of wetlands is a last resort option according to most resource agencies. Although the preferred sites are previous wetlands or damaged wetlands, areas where topography is advantageous may present a better choice. All sites should be evaluated using the process described previously. The evaluation process should become more and more detailed as the site selection process is narrowed. The hydrologic investigations should be in sufficient detail to determine whether the proposed site will meet the goals for the project but not necessarily to the detail required for design.

The first consideration is to determine if the site has sufficient area to meet the project goals. Associated with this question is the hydrology. Is the water supply sufficient in quantity and quality to support the wetlands? If the site has been a wetland, the size of the project should not be larger than the original wetlands unless there is an additional water supply. The drainage basin size and land use, both present and future, should be determined. If sediment is a problem, there should be sufficient area for a sediment trap. Buffer strips and vegetated upland areas around wetlands are often critical for the success of a project. If wildlife habitat is one of the goals, there is an additional need for a fenced buffer strip to protect the wildlife habitat from human and livestock intrusion.

If flood storage is an important functional value, then one of the more important considerations is where the site is located relative to the watershed. Sites near the headwaters of a watershed will provide for better flood storage effects and also have less sediment inflow problems, and the wetlands will be less affected by flood peaks. Adequate storage area should be available. The effects of flood flows on vegetation should be evaluated. Flood routing analysis of the watersheds is essential to account for timing of peak flows from the wetland and the watershed's subbasins. The location of a restored or created wetland in the lower portion of a basin may be subjected to more stress from floods than if it is located further upstream. A wetland may provide for local flood reduction but, in some unusual cases, may change the peak timing resulting in an increase in downstream flooding on the main stream. For this reason, a flood routing analysis is needed to determine if this condition may occur.

8.10.5 Detailed Evaluation of Proposed Site

Once the site is selected, a detailed site evaluation should be conducted, which should be similar to the initial site inspection but more detailed. An accurate topographic survey should be made. The accuracy of the survey should be controlled by the water depth tolerance of the proposed vegetation for the wetlands. Other items needed are aerial photography (preferably color infrared), planning maps, soils maps and land-use maps for the watershed. The color infrared photography will be useful in determining the extent of different types of vegetation.

A detailed groundwater investigation should be made. Soil test borings should be performed to determine the strata in the proposed wetland area. Soil permeability should be determined for each stratum encountered. If groundwater is one of the sources of water for the wetlands, the watertable needs to be defined and its seasonal fluctuations should be determined. If practical, the long-term variations in the watertable should be identified. This phase of the investigation may require the services of a groundwater specialist.

The basic hydrology for the site should be determined. This determination will depend on the location, topography and type of hydrology that occurs at the site. The data should include drainage area, land use, soil type, hydrologic parameters, time of concentration and rainfall data. The rainfall data should include an annual summary covering the length of record of the nearest long-term rain gage. From the records, select the wettest year of record, the driest year and a year of average rainfall. For each of these years, obtain daily rainfall records. This data will be used to develop a water budget for the wetlands.

For sites along streams, gage data should be analyzed if there are gages on the stream; see Section 7.8. If practical, a complete hydrograph of daily stream data for the wettest year of record, for the driest year and for an average precipitation year should be generated for the stream at the site location. This hydrograph will be the basis for the water budget developed for the proposed wetland. For ungaged streams, both high- and low-flow frequency discharge data should be computed using appropriate methods; see Chapter 7 "Hydrology."

8.11 THE WATER BUDGET

8.11.1 Design Process Overview

The water budget is the main hydrological tool used to evaluate wetland designs. This procedure is primarily for wetlands formed by impounding water. Alternative design approaches are briefly discussed in Section 8.12. For the general wetlands design process, see Section 8.10 and References (3), (4), (5), (10) and (22).

The water budget is basically a routing procedure that sums the water inputs into a wetland area, the outflows and the storage. All of these values are given in terms of water depth in the wetlands. Due to the sensitivity of vegetation to water depth, the desired computational accuracy should be to one inch. However, the hydrology will probably not be known or predicted to this level of accuracy. To be assured of the success of the wetland project, the designer should strive to provide an excess supply of water. The sensitive nature of vegetation to water depth requires that adequate control of the water level should be built into the project so that flooding of the growth area will not kill the new plants in the wetlands. Sufficient spillway capacity should be provided to pass the excess water without exceeding the requirements for the proposed vegetation.

The design procedure for the hydrologist involves:

- determining the adequacy of the water supply to meet the requirements for the proposed wetland vegetation by developing a water budget for the wetlands;
- designing water quality structures to remove sediment and other contaminants from the water before it enters the wetlands, if necessary; and
- designing the outlet control and outlet channel.

The hydrologist should also be involved in the construction plan preparation process and in establishing the construction sequence and time schedule. All design work should be accomplished in close cooperation with the Wetland Specialist.

8.11.2 Data Requirements

A substantial amount of data is needed for the water budget design. First is a detailed topographic survey of the wetland site. This may be developed by aerial mapping procedures supplemented with ground surveys. The survey should be sufficiently accurate to develop a contour map with contour intervals of 1 ft or 2 ft. The topographic survey of the site should be in sufficient detail to allow the designer to accurately establish appropriate grades and slopes to support wetland hydrology and vegetation. Standard USGS topographic mapping will probably be sufficiently accurate to determine hydrologic features such as drainage area and slope.

All data necessary to develop a hydrograph for the watershed should be determined. If the Natural Resources Conservation Service (NRCS) Method is used, the data required includes drainage area, land use, soil types, curve numbers and time of concentration. See Section 7.15.3. If there are any plans to change the land use in the watershed, the details of the proposed changes should be determined and incorporated into the wetland design.

Precipitation data requirements are very extensive. Rain gages located in the region around the wetland site should be identified and the data examined. The entire record of these gages should be studied to determine the wettest year of record, the driest year of record and the average year of record that would be representative of the wetland site. For each of these years, obtain the daily rainfall records. If the water supply will come from a stream that has a USGS gage, the complete hydrograph or the complete daily average discharge record for the entire length of record for the gage should be examined (see Section 7.8.2.3). Complete hydrographs for the wettest and driest years of record and an average year should be obtained. If the wetland is constructed on the edge of a lake or reservoir, daily lake levels that correspond to the wettest, driest and an average year should be obtained if the data is available. If the lake levels are not available, this data should be synthesized by using rainfall records, reservoir-operating procedures and routing procedures.

Caution is suggested in using entire period-of-record of rainfall and stream gages in urbanized areas or any area that has had large land-use changes. Urbanization can change rainfall patterns and amounts (rain shadows) and generally change the stage-discharge relationship, particularly affecting the peak discharge and timing of rising and falling limbs of the flood hydrograph.

The success of the wetlands is also a function of the geology of the area. A sufficient amount of geological data should be obtained for wetland development. The services of an experienced geologist or hydrogeologist may be necessary for this part of the design process. Soil hydraulic conductance or permeabilities of the different strata under the wetlands should be modeled. In some cases, soil borings may be necessary to better define the local geology. A sufficient number of piezometric test wells should be placed to define the hydroperiod of the watertable throughout the wetlands area. It is desirable that wells be in place for at least two years. If the wells are not monitored during a dry cycle, the time period should be longer or appropriate adjustments should be made to the levels.

8.11.3 The Water Budget Equation

The water budget equation is a form of the basic routing equation:

$$I - O = dS/dt \qquad \text{(Equation 8.1)}$$

where:

I = inflow per unit time, cfs
O = outflow per unit time, cfs
dS/dt = the change in storage per unit time, cu ft

Expressed in another way that can relate to the depth of water in the wetlands, the equation becomes:

$$\Delta V = \Delta t(I - O) \qquad \text{(Equation 8.2)}$$

and

$$\Delta D = \Delta V/A \qquad \text{(Equation 8.3)}$$

where:

V = the volume of water in the wetland, cu ft
A = the surface area of the water, sq ft
D = the depth of the water, ft
t = time, days or months

The water budget can be expressed in the following equation form that presents the inflows on the left and the outflows on the right:

$$P + SWI + GWI = ET + SWO + GWO + \Delta V/\Delta t \qquad \text{(Equation 8.4)}$$

where:

P = precipitation
SWI = surface water inflow
GWI = groundwater inflow
ET = evapotranspiration
SWO = surface water outflow
GWO = groundwater outflow
$\Delta V/\Delta t$ = change in storage

All terms are in units of depth of water in the wetlands, except V (cu ft) and t (days or months).

8.11.4 Precipitation

Precipitation is recorded at weather stations, which are usually located some distance from project sites. Many factors affect the accuracy of the weather station data and the transposing of data from these distant recording sites to the study area. These factors include:

- rain shadows;
- changes in elevation;
- lake effects;
- complex topography; and
- human activities including urbanization, deforestation and any large land-use changes.

When any of these factors is present, it may be necessary to obtain data close to the site. If extrapolation is necessary, a sound basis for extrapolation should be used. Rainfall extrapolation procedures are generally found in any good hydrology textbook.

The rainfall amount is a direct input into the wetland. However, part of the rain that falls will be intercepted by vegetation over the wetland. Good estimates for interception are generally not available except for forestlands. Studies of forest hydrology may be helpful. Mitsch and Gosselink (Reference (5)) indicate that the percentage of rainfall that is intercepted varies from 8 percent to 35 percent. The median value for deciduous forest is 13 percent and 28 percent for coniferous forest.

In the application of the water budget equation, precipitation (P) is usually combined with the surface water inflow term (SWI).

8.11.5 Surface Water

Surface water inflows can enter from several sources, including the following:

- direct runoff from the watershed in the form of sheet flow,
- shallow channel flow,
- stream flow, and
- overflow from a lake.

The important objective is to accurately determine the runoff. The hydrologic methods discussed in this Chapter can be used to determine runoff. Because designers are concerned with maintaining a desired water surface elevation in the basin, flow volume and its temporal distribution are the primary hydrologic variables to be determined. Measurements should be made to calibrate runoff models. When stream flow is a factor, computer models (e.g., HEC RAS) can be used to calculate water levels and velocities. Other methods for determining water levels and velocities include direct measurements and FEMA data. In hydraulically complex areas, use two-dimensional models; see Section 18.2.7. SWI in the application of the water budget equation is expressed as the volume in cu ft of flow during the calculation time step. The usual time step (Δt) is one month. With computer technology and sufficient data to support the effort, the time step may be reduced to achieve greater accuracy.

Check any impoundment structure to determine if it can safely pass greater magnitude floods (e.g., 100-year flood). Use standard pond routing procedures. For this purpose, calculate surface water outflow from the wetlands, using the weir equation or channel flow procedures; see Chapter 9 "Roadside Channels." In the water budget application, it is assumed that all water that exceeds the level of the weir during a time step will flow out over the weir. Then, SWO for a time step is equal to all volume that exceeds the volume of the basin at weir level.

8.11.6 Groundwater

Depending upon the hydrogeology of a wetland mitigation site, groundwater inflow may be significant to the hydrologic budget of a wetland (e.g., many glacial-landscape sites, sloped wetlands, many dry-climate sites). In contrast, if groundwater outflow (infiltration) from a potential wetland site is greater than the potential water inflow, maintaining a wetland on the site can be difficult, if not impossible. Unfortunately, groundwater data is more difficult and time-consuming to collect than surface water data. An experienced professional should collect the data. This effort is outside the scope of this Section. Additional information is available in Reference (23).

To determine groundwater flow into the wetland site, verify the water levels in unconfined or confined aquifers by installing monitoring wells. An above groundwater monitoring well is constructed with a well screen and casing. To properly set and seal well flow screens, the site hydrogeology should be understood and the type of aquifers present (e.g., confined, unconfined, leaky) should be known. The water level in an unconfined aquifer is referred to as the watertable, while the piezometric surface is used to describe the water level in a confined or leaky aquifer. Using the water levels in the well, the watertable and/or piezometric surface at the wetland site can be determined. Three wells in a single aquifer are used to determine the general direction of groundwater flow in that aquifer. Collect water level data over time because the direction of groundwater flow may vary over time. To determine the rate of groundwater flow, the hydraulic conductivity of the geologic materials and the hydraulic gradient should be determined. The hydraulic gradient is determined using the water level data and is usually expressed in terms of horizontal and vertical gradient. The volumetric flow rate is defined by Darcy's Law:

$$q = KA(dh/dt) \quad \text{(Equation 8.5)}$$

where:

q = the discharge, cfs
K = the hydraulic conductivity or permeability, ft/second
A = the cross-sectional area perpendicular to flow, cu ft
dh/dt = the hydraulic gradient, ft/ft

The basic data for defining groundwater flow are the direction and rate. Groundwater flow will vary seasonally into and out of the wetland.

Consider the effect that significant cutting or filling of earth areas near the proposed wetland mitigation site might have on the groundwater table elevation. For example, if a highway cut that is lower than the groundwater table is proposed up gradient of the mitigation site, it could draw down the watertable levels at the mitigation site.

8.11.7 Evapotranspiration

Evapotranspiration includes the surface evaporation of water and transpiration through plants. In wetlands, the evaporation from the water surface is usually affected by cover. Evaporation rarely adequately estimates total losses. Pan evaporation rates (evaporation from a shallow pan) are used to determine the ratio of total precipitation to total evaporation (P/E) for any specific region. Factors affecting evapotranspiration include the following:

- exposed water surface area,
- solar radiation,
- temperature of the air and the water,
- wind speed, and
- relative humidity.

Plants can control transpiration rates to some degree by closing leaf stomata. In dry areas, plants can activate water conservation measures when they experience dry conditions.

In wetlands, the vegetation reduces the evaporation rates. In marshlands, the exposed water surface area is reduced by the plants. Wind velocities at the water surface are reduced by the shielding effects of vegetation. At the water surface, microclimates exist as a result of the shielding effects of vegetation. These microclimates have higher humidity than the surrounding air. All of these effects reduce evaporation. Studies have shown that evapotranspiration rates vary from 30 percent to 90 percent of the rates from nearby open water.

The evaporation component can be reasonably estimated, but the transpiration component depends on knowledge of how much water the plants release through transpiration. The rates have been estimated to be from 0.53 to 5.40 times evaporation alone. In a pond, vegetation may reduce evaporation rates to approximately three-fourths of pan evaporation. Dry land transpiration may enhance evaporation beyond pan evaporation rates. In wetlands where supply overwhelms evapotranspiration, the need for evapotranspiration estimates is reduced. Calculated values may overestimate actual evapotranspiration rates. Evapotranspiration data may be available from state climatological centers.

There are several methods available to predict evapotranspiration. They vary in difficulty of application and accuracy. Either physical methods or climatologically based methods can be used to compute evapotranspiration. Physical methods use information on solar radiation and detailed information on transpiration specifically for the types of plants in the wetland. Climatologically based methods rely on temperature reports and require straightforward computations. These are readily used for wetland design. Modified climatologic methods are also straightforward. Pierce (Reference (3)) recommends the Thornthwaite-Mather method. NCHRP 397 (Reference (10)) also uses this method in an example problem. **The equation is presented only in SI units to avoid confusion.** The Thornthwaite Equation is:

$$PET = 16\left(\frac{10T_a}{I}\right)^a \qquad \text{(Equation 8.6)}$$

where:

PET = potential evapotranspiration, mm/month

T_a = mean monthly air temperature, °C

a = $0.49 + 0.0179(I) - 0.0000771(I)^2 + 0.000000675(I)^3$ (Equation 8.7)

and where the monthly heat index, I, is computed over a 12-month interval by the following equation:

$$I = \sum_{i=1}^{12}\left(\frac{T_a}{5}\right)^{1.5} \qquad \text{(Equation 8.8)}$$

The formula is for a standard month of 30 days of daylight and must be adjusted to latitude and month according to Figure 8.11-A. The adjustment is made by multiplying the calculated PET by the correction factor in the table.

8.11.8 Water Budget Computation Procedures

The procedures given here use the NRCS Curve Number approach to determine runoff (see Section 7.15.3) and the Thornthwaite evapotranspiration procedures, Equation 8.6.

Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
60 N	0.54	0.67	0.97	1.19	1.33	1.56	1.55	1.33	1.07	0.84	0.58	0.48
50 N	0.71	0.84	0.98	1.14	1.28	1.36	1.33	1.21	1.06	0.90	0.76	0.68
40 N	0.80	0.89	0.99	1.10	1.20	1.25	1.23	1.15	1.04	0.93	0.83	0.78
30 N	0.87	0.93	1.00	1.07	1.14	1.17	1.16	1.11	1.03	0.96	0.89	0.85
20 N	0.92	0.96	1.00	1.05	1.09	1.11	1.10	1.07	1.02	0.98	0.97	0.96
10 N	0.97	0.98	1.00	1.03	1.05	1.06	1.05	1.04	1.02	0.99	0.97	0.96
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Source*:* Reference (5)

Figure 8.11-A — CORRECTION FACTORS FOR MONTHLY SUNSHINE DURATION

Other runoff and evapotranspiration methods may be more appropriate in particular areas:

Step 1 Obtain Basic Data for Site

a. Soils data including soil types and soil permeabilities.

b. Topographic survey data for site.

c. Watershed data including NRCS soil type (A, B, C or D), land use, present and future urbanization, historic rainfall data, daily rainfall data for wettest, driest and average year, historic mean monthly temperatures.

Step 2 Calculate Runoff from Watershed

All calculations are done on a monthly basis:

a. Map the NRCS soil types. Determine the extent of each soil type in watershed in acres.

b. Map the land uses for the watershed.

c. Overlay the land-use map over the soil type map. This will divide the watershed into sub-areas based on land use and soil type.

d. Determine NRCS curve numbers (CN) for each sub-area.

e. Determine weighted curve number for watershed using the equation:

$$CN_{weighted} = \frac{\sum_{i=1}^{n}(CN_i)(A_i)}{\sum_{i=1}^{n}A_i} \quad \text{(Equation 8.9)}$$

where:

CN_i = NRCS curve number for sub-area i
A_i = area of sub-area i
N = number of sub-areas

f. Determine the wettest year, the driest year and an average year from the rainfall data.

g. Determine the minimum amount of precipitation that will cause runoff. This is done graphically by finding the point where the runoff curve number line intersects the horizontal axis or by setting the rainfall-runoff equation (in Section 7.15.3) equal to zero and solving for P:

$$Q = (P - 0.2S)^2/(P + 0.8S) \quad \text{(Equation 8.10)}$$
$$0.0 = (P - 0.2S)^2/(P + 0.8S)$$
$$(P - 0.2S)^2 = 0.0$$
$$P = 0.2S \quad \text{(Equation 8.11)}$$

where:

$$S = 25.4\ [(1000.0/CN) - 10.0] \quad \text{(Equation 8.12)}$$

$$\text{Therefore, } P = (5080/CN) - 50.8 \quad \text{(Equation 8.13)}$$

h. Calculate runoff depth, Q, for all precipitation events large enough to produce runoff. This can be done by solving Equation 8.10.

i. Calculate the runoff volume for the watershed by multiplying the runoff depth, Q, by the drainage area in square feet: Volume = (Q)(A)

j. Convert the runoff volume to depth over the wetlands.

Step 3 Calculate Potential Evapotranspiration (PET)

Use evapotranspiration data from NOAA and compare with South Dakota average data (see Figure 13.10-A). If data is questionable or not available, use the Thornthwaite Equations (Equations 8.6, 8.7 and 8.8) to calculate PET. Adjust the PET for latitude and month using values from Figure 8.11-A.

Step 4 Determine Groundwater Influences

a. Determine groundwater outflow (infiltration). The rate is equal to the hydraulic conductivity of the soil, K, in units of ft/month.

b. Determine groundwater inflow. A conservative estimate will be to assume that this is zero.

Step 5 Tabulate Results

a. Express all inflows and outflows as depth over wetland site (usually to a reference datum). Divide volumes by site area to get depth. Precipitation and infiltration are usually already expressed as depth.

b. Determine storage, S, in terms of depth over wetland area including any storage from previous month:

$$S = \sum \text{Inputs} - \sum \text{Outputs} + S\ (\text{Previous}) \qquad \text{(Equation 8.14)}$$

c. If the depth is greater than the height of the control structure, usually a weir, the depth will equal the height of the control structure. If it is less than the bottom of the wetlands, it is equal to the bottom of the wetlands.

d. Plot the results by month to determine the drawdown regimes.

8.11.9 Example Wetland Water Budget Problem

See Appendix 8.A.

8.12 WETLAND DESIGN BY ELEVATED GROUNDWATER

Alternative wetland restoration design procedures do not rely on flooding of the wetlands but rather on saturation of the soil through elevating the groundwater table. Several structural methods are available to accomplish this. One method is to raise the water level in existing channels or streams by constructing a dam or dike in the channel. Another method is to construct a series of channels and/or ponds throughout the wetland area. These channels and ponds can be filled by some water source.

The hydrologic analysis for this type of design will consist of two parts. The first is an analysis of the water supply. If the supply is from a stream that has a gage, the gage data should be analyzed to determine the discharges for the wettest and driest years of record and an average year. For ungaged streams, this analysis must be performed by computing hydrographs to predict the expected water supply.

The second part of the analysis is to analyze the groundwater flow to confirm that the watertable will be raised to the appropriate levels during the required time in the growing season. This type of analysis is outside the scope of this *Manual* and should be performed by a qualified groundwater specialist. There is at least one computer program available to do this type of analysis, DRAINMOD developed by R.W. Scaggs of North Carolina State University and adopted by NRCS. NRCS has South Dakota specific climatic data available on its website. The groundwater specialist may recommend using DRAINMOD to the Leader of the Wetland Creation/Restoration Project Team. If the soils are highly permeable, the groundwater analysis may not be required. However, groundwater monitoring wells should be used to assure that the required groundwater levels are achieved and maintained.

8.13 SPECIFIC FEATURES OF DESIGN

This Section discusses the structural and functional features that should be considered in the design of wetlands. Design criteria for large storage facilities are found in Section 13.3. Construction and maintenance considerations are found in Section 13.11.

8.13.1 Shape, Size and Contours of the Wetlands

The shape of the wetlands should reflect the general topography of the area in which it is located. Natural shapes are more aesthetically pleasing and should be used as a model. Standard geometric shapes should be avoided. The size of the wetlands is dictated by the established goals and by the water supply capacity of the watershed. Contouring of the wetland bottom should be gradual or irregular. A very gradually sloped bottom will enhance the depth and drawdown requirements of the vegetation.

8.13.2 Protection of the Wetlands by Treatment of Inflow and Buffer Strips

Water quality is one of the concerns in wetland design. The quality of the water supply should be compatible with the proposed vegetation. In watersheds that include urban or industrial development, agricultural lands and high-energy streams, surface waters may need treatment to remove sediment and pollutants. Most wetland plants are very effective at pollutant removal, so a pretreatment wetland may be needed to purify the water before it enters the main project area. Good access to the sediment ponds or traps will be needed for the removal of excessive sediments. Where sediment ponds are expected to be permanent features of the wetlands, a maintenance schedule should be developed to remove the accumulated sediments from the sediment trap. Sufficient funding should be available to finance the maintenance. Where overland flow from agricultural land or other disturbed land flows into the wetland area, a vegetated buffer strip may be needed to remove sediment and pollutants.

8.13.3 Channel Design

If stream channels will be constructed as part of the wetland project, they should be wide and shallow with a parabolic cross section to reduce water velocities. Slopes should be as flat as practical to reduce the erosion potential. Flow deflectors should be placed approximately every 100 ft to force meandering. If practical, slope changes should be avoided. If a slope change cannot be avoided, stable channel design procedures given in Chapter 9 “Roadside Channels” should be used to prevent erosion.

8.13.4 Outlet Control Structure and Outfall Channel

The outlet control structure is one of the most important components of a wetland project that is based on the impoundment of water. It is the feature that controls the water level in the wetland. It will usually consist of a berm, dike or dam. Any dam structure should be constructed in compliance with appropriate dam safety regulations. The structure should be constructed as a low-maintenance structure. To mitigate problems due to burrowing by rodents, it should have 10H:1V sloped sides with a broad top. Wetland control structures are usually low-head structures from 1 ft to 2 ft high. If greater water depths are needed in the wetlands, the area may be excavated upstream from the dam with a shallow berm separating the deeper area from the dam. This will reduce the head on the dam and reduce the potential for leakage. This type of design has a number of important features:

- large quantities of soil can be placed in the dam even though it is low;
- the need for a core is reduced;
- the danger of a piping failure along tree roots is reduced;
- the wide top can be used for vehicular or pedestrian traffic;
- burrowing animals will seek steeper banks for den sites, if available;
- the flat slopes will provide a gradual depth change, maximizing drawdown and increasing plant diversity and vigor; and
- the dike top can be used to increase upland habitat diversity.

A spillway should provide the actual water depth control. This structure should be constructed with removable flashboards or other adjustable controls. The control elevation should be adjustable to the order of 1 in. The spillway should be designed to handle the 100-year flood. Because of the broad width required, the spillway may need to be designed as a weir or a channel.

8.14 CONSTRUCTION CONSIDERATIONS

Adequate planning and design can be nullified by improper construction techniques that are not compatible with the goals of the project. A good set of plans and specifications is required. Two of the more important ways to educate the contractor on the sensitive nature of the project are:

- make the contractor aware of design specifications and logistics through one or more preconstruction meetings; and
- provide on-site supervision by a qualified wetland specialist, preferably the one who designed the system.

Highly disturbed areas such as dikes, channels, berms and other control areas should be designed and constructed so that, in a few years, they can be removed or otherwise obscured from the scene. Permanent fixtures should be constructed to blend with the area.

Soil stabilization is essential for newly prepared sites to prevent soil erosion and to prevent the formation of gullies. This can be achieved though cover planting and contouring. Contouring should be accomplished with careful attention to elevation and the watertable. Contours should be as gentle as practical.

During construction, areas may need to be de-watered, or the watertable may need to be lowered. Restoration of such wetlands may need a dam or water control structure. Methods of de-watering include pumps, ditches and drawdown wells. Consideration should be given to the effects of the water on downstream areas. Sediment and erosion control should be among the considerations.

For many situations, it may be desirable to supply additional water during the establishment period. This may be especially true in highly permeable soils. The source for the water may be trucking, which can be very expensive. In the more arid regions of the State, water rights may be acquired to secure the additional water.

Timing of construction is critical. Close coordination with the construction schedule and the seeding or planting schedules should be maintained. Ideally, wetland construction should be completed just before the prime planting season so that there is a minimum of exposure time between the earthwork completion and the planting of cover. Erosion and soil stabilization are the primary concerns. It may be necessary to plant a temporary cover crop until the wetland vegetation can be established.

8.15 MONITORING

An important aspect of a wetland creation/restoration project is monitoring. This is primarily the responsibility of the wetland specialist. Monitoring serves several important purposes:

- Monitoring will measure the progress of the vegetation and wildlife establishment in the wetlands.
- Monitoring will provide a measurement of how well the original goals of the project are met and provide a learning experience for future projects.
- The most sensitive time for vegetation is in the early stages of development. Hydric soils require two to three years to develop with appropriate wetland hydrology. The monitoring should be performed to ensure that the water needs of the vegetation are adequately met. Corrections or adjustments in water supply or depth may be required. If such adjustments are apparent, the other team members should also be involved so that future actions can be correlated.
- Replanting may be needed if vegetation is damaged or fails.
- Repairs may be needed if damage from human or animal action occurs.
- Invading nuisance species may need to be removed by mechanical means or herbicides.

Monitoring should be done on a schedule established during the planning stage of the project. The time frame over which monitoring may be required will depend on the type of wetlands being established and may be established by regulations or regulatory agencies. The services of the hydrologist may be needed if large adjustments are needed in the water supplies. However, the original design should incorporate sufficient adjustment to accommodate most required changes.

8.16 REFERENCES

(1) USGS Water Supply Paper 2425, *National Water Summary — Wetland Resources: State Summaries*: "South Dakota Water Resources," 2000.

(2) *AASHTO Model Drainage Manual*, 2005.

(3) Pierce, G. J. (Southern Tier Consulting, Inc.), *Planning Hydrology for Constructed Wetlands*, Wetland Training Institute, Inc., Poolesville, MD, 1993.

(4) Hammer, D. A., *Creating Freshwater Wetlands*, CRC Press/Lewis Publishers, Inc., Boca Raton, FL, 1992.

(5) Mitsch, W. J. and Gosselink, J. G., *Wetlands*, Second Edition, Van Nostrand Reinhold, New York, 1993.

(6) Kusler, J. A. (Association of State Wetland Managers), "Hydrology: An Introduction for Wetland Managers," ASWM Technical Report 6, *Proceedings of the National Wetland Symposium: Wetland Hydrology*, Association of State Wetland Managers, Berne, NY, September 16–18, 1987.

(7) Beissel, Kelly D. and Shear, Theodore H., "Comparison of Vegetational, Hydrologic and Edaphic Characteristics of Riverine Forested Wetlands on North Carolina Coastal Plain," Transportation Research Record No. 1601, Transportation Research Board, National Research Council, National Academy Press, Washington, DC, 1997.

(8) Broome, S. W., "Creation and Restoration of Tidal Wetlands of the Southeastern United States," in *Wetland Creation and Restoration, the Status of the Science*, Island Press, Washington, DC, 1990, pp. 37–72.

(9) Clewell, A. F. and Lea, R., "Creation and Restoration of Forested Wetland Vegetation in the Southeastern United States," in *Wetland Creation and Restoration, the Status of the Science*, Island Press, Washington, DC, 1989, pp. 195–230.

(10) Denbow, T. J., Klements, D., Rothmen, D. W. (URS Consultants, Inc.), Garbisch, E. W., Bartoldus, C. C., Kraus, M. L., MacLean, D. R. and Thunhorst, G. A. (Environmental Concern, Inc.), *Report 397: Guidelines for the Development of Wetland Replacement Areas*, National Cooperative Highway Research Program, National Academy Press, Washington, DC, 1996.

(11) Erwin, K. L (Kevin L. Erwin Consulting Ecologist, Inc.), "Freshwater Marsh Creation and Restoration in the Southeast," in *Wetland Creation and Restoration, the Status of the Science*, Island Press, Washington, DC, 1990.

(12) Hollands, G. G. (IEP, Inc.), "Regional Analysis of the Creation and Restoration of Kettle and Pothole Wetlands," in *Wetland Creation and Restoration, the Status of the Science*, Island Press, Washington, DC, 1990.

(13) Jenson, S. E. (White Hourse Associates) and W. S. Platts (Platts Consulting), "Restoration of Degraded Riverine/Riparian Habitat in the Great Basin and Snake River Regions," in *Wetland Creation and Restoration, the Status of the Science*, Island Press, Washington, DC, 1990.

(14) Josselyn, M. (Romberg Tiburon Center Environmental Studies, San Francisco State University), Zedler, J. and Griswold, T. (Pacific Estuarine Research Laboratory San Diego State University), "Wetland Mitigation Along the Pacific Coast of the United States," in *Wetland Creation and Restoration, the Status of the Science*, Island Press, Washington, 1990.

(15) Kusler, J. A. and Brooks, G., editors, ASWM Technical Report 6, *Proceedings of the National Wetland Symposium: Wetland Hydrology*, Association of State Wetland Managers, Berne, NY, September 16–18, 1987.

(16) "Field Guide for Wetland Delineation," *USACE Manual*, Wetland Training Institute, 1987.

(17) South Dakota State University, College of Agriculture and Biological Sciences, "Guidelines for Restoring and Creating Wetlands Associated with Highway Projects in South Dakota," March 2000.

(18) *Corps of Engineers Wetlands Delineation Manual*, Technical Report Y-87-1, Environmental Laboratory, Department of the Army, Waterways Experiment Station USACE, Vicksburg, MS, January 1987.

(19) Fredrickson, L. H. and Taylor, T. S., *Management of Seasonally Flooded Impoundments for Wildlife*, United States Department of Interior, Fish and Wildlife Service Resource Publication 148, Washington, DC, 1982.

(20) Kusler, J. A. and Kentula, M. E., editors, *Wetland Creation and Restoration, the Status of the Science*, Island Press, Washington, DC, 1990.

(21) Willard, D. E., Finn, V. M., Levine, D. A., and Klarquist, J. E. (School of Environmental Affairs, Indiana University), "Creation and Restoration of Riparian Wetlands in the Agricultural Midwest," in *Wetland Creation and Restoration, the Status of the Science*, Island Press, Washington, DC, 1990.

(22) Westbrook, Thomas A., *Calculating a Water Budget for Use in Construction of Wetlands,* USACE, Norfolk District, July 1994.

(23) Freeze, Allan R. and Cherry, John A., *Groundwater*, Prentice-Hall, Englewood Cliff, NJ, 1979.

Appendix 8.A

WETLAND WATER BUDGET PROBLEM

A wetland mitigation site is proposed for construction just upstream of Secondary Road S-55 on a tributary to Black Creek. The location of the site is at approximately 34 degrees latitude. An adjustable control structure will be built at the upstream end of the culvert under the road. It will be set to establish a design water depth in the wetland equal to 3.3 ft. The wetland will occupy the creek bed and floodplain of the creek. The soils in the proposed wetlands are highly impervious, so there will be no direct groundwater inflow into the wetlands. The stream is spring fed. Therefore, it has a moderate base flow. To define this base flow, a stream gage was set up for two years at the site and a minimum flow of 0.07 cfs was determined. After the location studies were made, the following data was assembled:

Step 1 Data for Wetland Site on Secondary Road S-55 on tributary to Black Creek

- The permeability of the soil for the wetlands was determined to be K = 3.15 x10^{-6} in/seconds or 0.69 ft/month.
- A topographic map as shown in Figure 8.A-A.
- Monthly rainfall at the Columbia Weather station for years 1948 – 1996 (Figure 8.A-B).
- Daily rainfall for 1954 (Figure 8.A-C), identified as the driest year.
- Daily rainfall for 1964 (Figure 8.A-D), identified as the wettest year.
- Daily rainfall for 1968 (Figure 8.A-E), identified as an average year.
- Monthly average temperatures for these same years (Figure 8.A-F).
- The planned wetlands will have a gradually sloping bottom, which will have a depth-to-volume relationship as shown in the graph in Figure 8.A-G.

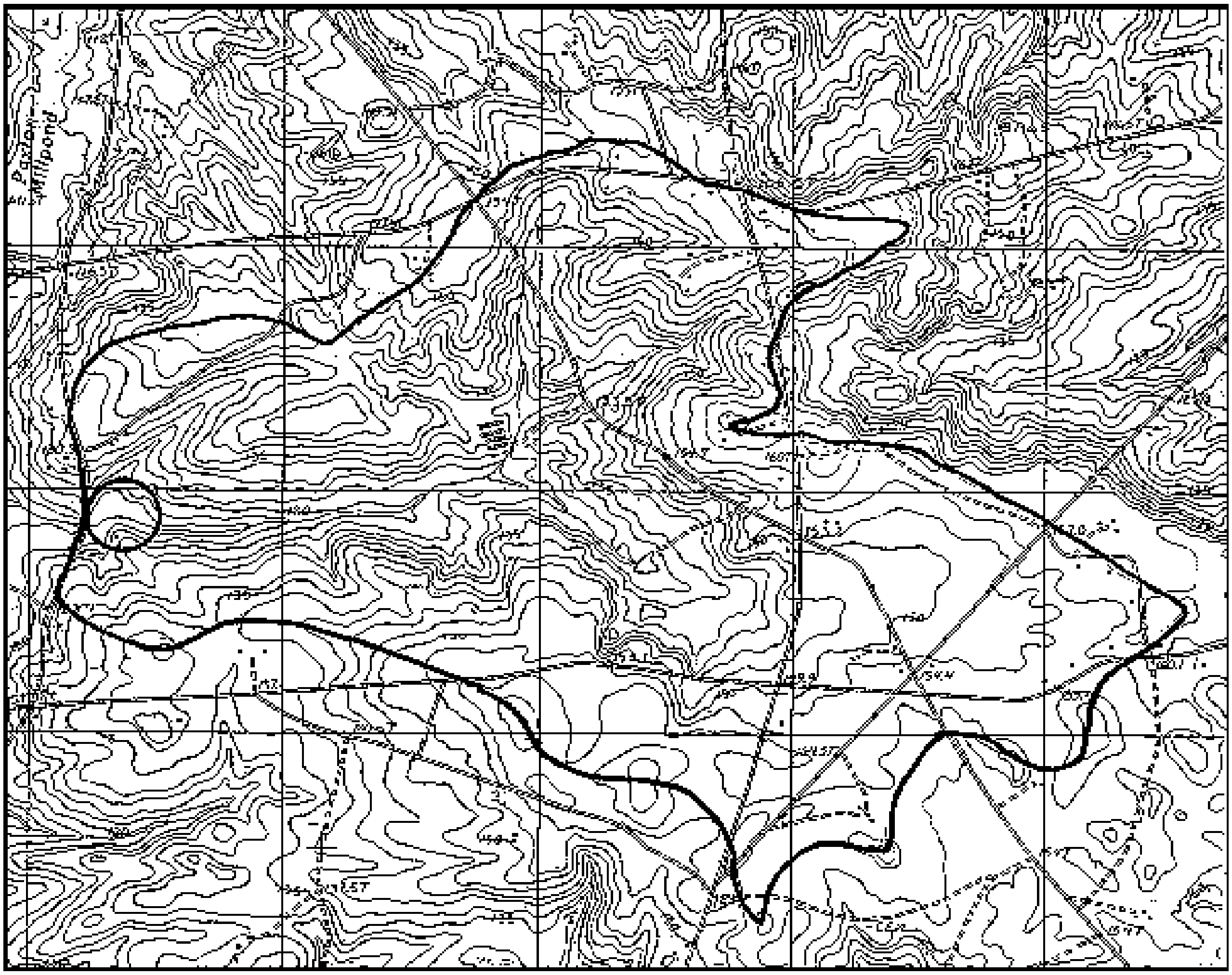

Figure 8.A-A — TOPOGRAPHIC MAP OF WATERSHED FOR EXAMPLE PROBLEM

Yr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1948	-9.99	-9.99	-9.99	-9.99	-9.99	-9.99	2.60	2.76	7.29	3.50	6.85	3.85	-9.99
1949	0.97	6.38	1.25	5.51	2.34	1.70	5.36	16.7	2.63	2.38	1.01	1.62	47.9
1950	2.77	1.12	4.16	1.37	4.45	3.55	11.8	4.72	6.46	1.34	1.70	3.52	47.0
1951	1.50	1.42	4.85	4.87	0.29	4.79	8.16	1.27	4.70	0.67	2.31	3.76	38.6
1952	3.46	4.31	7.00	3.10	3.47	2.44	1.17	120	2.65	0.70	1.58	3.64	45.5
1953	1.98	5.55	3.70	3.41	3.49	6.46	4.25	6.81	8.78	0.32	1.28	7.43	53.5
1954	1.91	2.26	2.44	2.09	2.20	1.49	2.24	5.91	1.75	1.23	1.92	1.94	27.4
1955	4.90	2.17	2.00	4.01	3.00	1.26	2.95	4.79	1.38	2.55	2.13	0.32	31.5
1956	1.73	5.45	3.99	5.31	1.92	1.70	3.68	1.77	7.94	1.83	0.66	2.44	38.4
1957	2.48	1.30	4.59	2.25	6.71	1.86	1.15	4.12	6.74	1.80	7.20	2.44	42.6
1958	4.09	3.87	4.47	5.89	3.79	3.61	8.70	1.93	0.76	2.65	0.58	3.85	44.2
1959	2.94	4.99	6.28	2.64	5.79	2.67	13.9	4.52	7.12	12.1	0.67	2.42	66.0
1960	7.15	5.56	6.17	3.91	1.47	2.37	4.79	5.52	3.94	1.71	0.68	2.37	45.6
1961	2.93	8.68	5.75	5.52	2.55	1.95	5.70	13.6	1.46	0.82	1.01	3.21	53.2
1962	6.49	4.83	4.40	3.21	2.32	4.78	2.67	3.10	2.85	0.89	4.53	2.27	42.3
1963	5.38	3.94	3.28	4.18	2.87	4.84	2.48	1.91	3.98	0.00	4.20	5.05	42.1
1964	6.34	5.33	6.16	3.60	2.63	2.97	10.3	9.97	6.93	10.3	1.36	4.58	70.5
1965	1.43	5.33	7.68	3.99	1.46	8.20	4.33	9.39	5.99	2.34	1.77	0.64	52.6
1966	7.22	4.54	2.23	3.58	6.14	3.66	2.87	3.22	2.02	2.47	1.05	3.31	42.3
1967	2.79	4.36	3.08	3.72	8.85	4.18	7.27	11.2	2.38	0.62	3.71	2.59	54.7
1968	5.94	1.14	1.92	4.52	4.17	5.41	9.28	1.11	2.40	4.31	5.21	3.26	48.7
1969	2.64	3.03	5.16	4.57	3.28	4.70	4.31	2.93	3.17	1.17	1.20	4.51	40.7
1970	3.28	2.58	8.42	0.91	4.50	2.05	4.74	7.13	3.72	8.18	1.43	4.55	51.5
1971	4.55	5.23	9.53	4.31	2.71	7.46	11.1	10.7	5.03	3.44	2.35	2.9	69.3
1972	7.62	3.58	3.79	1.16	6.41	6.10	9.31	2.87	2.51	1.15	5.62	5.39	55.5
1973	5.25	5.75	10.9	4.47	4.04	14.8	3.19	6.92	4.47	0.71	0.41	6.66	67.6
1974	6.16	4.49	2.36	2.97	3.40	4.50	4.40	6.20	4.44	0.02	4.47	4.61	48.0
1975	4.26	6.43	5.41	4.59	7.88	2.85	9.91	3.16	3.32	0.88	2.23	5.03	56.0
1976	3.58	0.87	5.24	0.81	4.63	11.7	6.55	1.02	5.74	5.21	5.13	7.54	58.0
1977	4.20	1.22	6.34	0.91	0.89	2.20	0.57	10.7	1.51	4.81	2.10	3.69	39.2
1978	9.26	1.28	3.49	4.28	3.09	4.73	2.10	4.45	4.09	0.79	2.98	1.82	42.4
1979	5.19	8.10	3.53	6.85	6.47	5.48	7.28	4.05	7.86	1.76	3.89	1.51	62.0
1980	4.72	1.88	10.70	2.02	4.51	2.27	1.24	3.29	7.25	1.58	1.72	1.33	42.5
1981	0.84	4.08	2.25	1.87	3.38	5.28	5.42	4.65	0.39	1.90	1.47	8.54	40.1
1982	3.74	4.39	1.65	6.44	2.92	4.23	9.98	5.88	3.32	1.47	2.62	3.72	50.4
1983	3.66	5.38	7.35	5.68	0.70	2.85	0.73	3.36	3.25	2.22	3.63	6.58	45.4
1984	3.99	4.88	5.54	3.75	4.29	6.47	8.69	3.23	0.67	1.03	0.78	1.75	45.1
1985	3.27	7.15	0.56	1.29	3.13	3.96	7.47	5.65	0.07	8.44	5.98	0.88	47.9
1986	1.05	1.46	3.21	0.35	1.13	0.88	1.25	9.55	0.56	6.04	6.26	2.52	34.3
1987	8.36	5.39	5.38	0.40	1.12	6.49	3.95	10.8	5.27	0.99	4.55	1.55	54.2
1988	4.10	2.02	1.98	3.01	2.08	1.66	3.24	11.8	7.53	3.68	1.59	0.75	43.4
1989	1.90	3.30	4.89	4.27	4.44	5.99	9.41	3.19	5.16	2.25	1.85	5.28	51.9
1990	2.44	2.56	2.28	1.26	4.03	1.27	5.14	6.51	2.64	11.7	2.04	1.64	43.5
1991	5.48	1.87	7.57	4.69	6.96	3.56	17.5	7.77	2.45	0.54	1.46	2.62	62.4
1992	3.14	4.16	3.38	3.16	1.93	6.37	2.15	9.61	4.60	4.22	4.02	3.26	50.0
1993	7.49	3.29	6.01	1.63	2.98	0.74	2.02	2.34	3.90	4.29	1.94	2.39	39.0
1994	4.16	4.06	4.49	0.29	1.99	11.10	3.70	5.31	3.27	4.74	3.08	5.83	52.0
1995	4.49	6.70	1.70	0.98	1.69	10.70	7.86	6.69	5.51	3.61	2.89	2.19	55.1
1996	2.90	1.16	6.52	2.38	2.68	1.34	3.36	-9.99	-9.99	-9.99	-9.99	-9.99	-9.99
Avg	4.15	3.88	4.76	3.20	3.51	4.47	5.62	6.03	3.93	2.93	2.60	3.40	48.56

**Figure 8.A-B — STATION: (381939) COLUMBIA_WSFO_AP-
TOTAL PRECIPITATION (in) FROM YEAR 1948 TO 1996**

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0	0	0.07	0.02	0.20	0.30	0	0.03	0	0	0	0
2	0	0	0	0	0	0.01	0.11	0.43	0	0	0	0
3	0	0	0.07	0	0.24	0.72	0	2.48	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0.31	0
5	0	0	0	0	0	0	0	0	0	0	0.12	0.80
6	0	0	0	0	0	0	0	0	0	0	0	0.09
7	0	0	0	0	0	0	0.08	0	0	0	0	0
8	0	0	0	0.05	0.03	0	0	0	0	0.01	0	0
9	0	0	0	0.45	0	0	0.03	0.83	0	0.12	0	0.12
10	0.12	0	0	0.01	0	0.05	0	0	0	0.86	0	0
11	0.46	0	0	0	0	0.27	0	0	0.26	0	0	0
12	0	0	0	0	0	0	0	0	0.28	0	0	0
13	0	0	0.45	0	1.26	0	0.27	0	0	0	0	0.76
14	0.03	0	0.08	0.34	0.20	0	0	0	0	0	0.05	0.01
15	0.01	0	0	0.79	0	0	1.06	0	0	0	0.02	0
16	0.65	0.31	0	0.04	0	0	0.60	0	1.21	0	0.19	0
17	0	0	0	0.03	0	0.12	0	0.21	0	0	0.01	0
18	0	0	0	0	0	0.02	0	0	0	0	0.47	0.02
19	0	0	0.54	0	0	0	0	0	0	0	0	0.13
20	0	0.15	0	0	0.04	0	0	0	0	0	0.20	0
21	0.06	0.07	0	0	0	0	0	0	0	0	0	0
22	0.58	0	0	0.36	0	0	0.03	0.06	0	0	0	0
23	0	0	0.12	0	0	0	0	0.40	0	0	0.25	0
24	0	0.29	0.11	0	0	0	0	0	0	0	0.01	0
25	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0.12	0	0	0	0.05	0	0	0	0	0
27	0	0	0.3	0	0	0	0	0.02	0	0	0.01	0
28	0	1.44	0.07	0	0.12	0	0	1.45	0	0.20	0.28	0
29	0	0	0.07	0	0.11	0	0	0	0	0.04	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0.44	0	0	0	0.01	0	0	0	0	0.01
Sum	1.91	2.26	2.44	2.09	2.2	1.49	2.24	5.91	1.75	1.23	1.92	1.94

Figure 8.A-C — STATION: COLUMBIA (STATION ID 381939)
YEAR: 1954 PRECIPITATION (in)

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.07	0	0	0	0	0.26	0	0	0	0.05	0	0
2	0	0	1.20	0	2.05	0.03	1.13	0	0	0.14	0	0
3	0	0	0	0.05	0.52	0	0	0	0	0.15	0	0.36
4	0	0	0.04	0	0	0	0.58	0	0	1.27	0	0.40
5	0	0.73	0.15	0	0	0	0	0	0	2.56	0	0.05
6	0.27	0.02	0	1.78	0	0.45	0	0	0	0	0	0
7	0.05	0.19	0	0.02	0	0.48	0	0	0	0	0	0
8	0.55	0.16	0	0.51	0	0	0	0	0	0	0	0
9	1.38	0	0	0	0	0	0	2.49	0	0	0	0
10	0	0.01	0.07	0	0	0	0.07	1.41	0	0	0	0
11	0.05	0.12	0	0	0	0	0.01	0.30	0	0	0	0
12	1.38	0	0	0	0	0	0.06	0	2.83	0	0	0.17
13	0.01	0.45	0	0.10	0	0.26	0.40	0	0.40	0	0	0
14	0	0.06	0.63	0	0	0	0.03	0	0	0.02	0	0
15	0	0.76	1.38	0	0	0	0	0.08	0	4.09	0	0
16	0.18	0.01	0	0	0	0	0.16	0.29	0	2.02	0	0
17	0.44	0	0	0	0	0	0.83	0.07	0	0	0	0.1
18	0	1.45	0	0	0	0.1	1.04	0	0	0	0	0.01
19	0	0	0.20	0	0	0	1.71	0	0	0.03	0	0
20	0.75	0	0.20	0	0	0	0.90	0	0	0.01	0.81	0.27
21	0	0	0.03	0	0	0.04	1.52	0	0	0	0	0
22	0	0	0	0	0	0.51	0.90	0	0	0	0	0
23	0	0	0	0	0	0.06	0.03	0	0	0	0	0
24	0.54	0	0.03	0.02	0	0.24	0.17	0	0	0	0.34	0
25	0.49	0.54	1.71	0.12	0	0.49	0	0	0	0	0.21	0.35
26	0	0	0.52	0	0	0.05	0	0	0	0	0	2.86
27	0	0.47	0	1.00	0	0	0.07	0	0.04	0	0	0
28	0	0.36	0	0	0.06	0	0.01	0.25	0.10	0	0	0.01
29	0	0	0	0	0	0	0	4.20	0	0	0	0
30	0	0	0	0	0	0	0.70	0.61	3.56	0	0	0
31	0.18	0	0	0	0	0	0	0.27	0	0	0	0
Sum	6.34	5.33	6.16	3.60	2.63	2.97	10.32	9.97	6.93	10.34	1.36	4.58

Figure 8.A-D — STATION: COLUMBIA_WSFO_AP (STATION ID 381939)
YEAR: 1964 PRECIPITATION (in)

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.49	0	0	0	0	0	0	0	0.12	0	0	0.55
2	0.08	0.20	0	0	0.09	0.22	0	0	0	0	0	0.05
3	0.10	0	0	0.45	0	0	2.16	0	0	0	0	0.57
4	0.26	0	0	0	0.09	0	1.46	0	0	0	0	0.11
5	0	0	0	0.57	0.03	0	0.98	0.02	1.69	0.95	0	0
6	0.28	0	0	0	0	0	0	0	0	0.1	0	0
7	0.03	0	0	0	0	1.25	0	0	0	0.15	0	0
8	0	0	0	0	0	0.43	0	0	0	0	1.19	0
9	0.16	0	0	0.64	0	1.53	1.51	0	0.12	0	0.06	0
10	2.79	0	0.65	0.08	0	0.04	0.83	0	0	0	1.50	0
11	0.02	0	0.25	0	0.12	0	0.28	0.24	0	0	0.09	0
12	0.73	0	0.26	0	0.08	1.17	0.51	0.06	0	0	0	0
13	0.20	0	0	0	2.08	0	0	0.10	0	0	0	0
14	0	0	0	0	0.45	0	0	0	0	0	0	0.17
15	0	0	0	0.17	0	0	0	0	0	0.11	0.13	0
16	0	0	0.34	0	0.26	0	0	0	0	0.28	0	0
17	0	0	0.01	0	0.19	0.16	0	0	0	0.12	0.25	0
18	0	0	0	0	0.21	0.04	1.04	0	0	2.60	0	0
19	0	0	0	0	0	0	0.48	0.19	0	0	0	0
20	0	0	0	0	0	0	0	0.03	0	0	0	0
21	0	0.05	0	0	0	0	0	0	0	0	0	0
22	0	0.05	0.03	0	0	0	0	0	0	0	0	0.50
23	0	0	0.16	0.13	0	0.17	0	0	0	0	0	0.30
24	0.79	0.02	0	0.35	0	0.40	0	0.08	0	0	0	0
25	0.01	0	0	0	0.04	0	0	0.17	0	1.99	0	0
26	0	0	0	0	0.44	0	0	0	0.47	0	0	0
27	0	0	0	0.04	0	0	0	0	0	0	0	0
28	0	0.02	0	0.22	0	0	0	0	0	0	0	0.52
29	0	0.8	0	1.87	0.09	0	0	0	0	0	0	0
30	0	0	0.20	0	0	0	0.03	0	0	0	0	0
31	0	0	0.02	0	0	0	0	0.22	0	0	0	0.49
Sum	5.94	1.14	1.92	4.52	4.17	5.41	9.28	1.11	2.4	6.30	3.22	3.26

Figure 8.A-E — STATION: COLUMBIA_WSFO_AP (STATION ID 381939)
YEAR: 1968 PRECIPITATION (in)

Mean Daily Temperature (°F)

Year 1954

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
47.3	52.3	54.5	66.8	66.5	79.9	83.9	83.1	78.1	65.3	50.4	44.6

Year 1964

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
44.1	43.7	54.8	64.2	72.4	80.5	78.8	78.4	73.8	59.1	58.2	49.8

Year 1968

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
41.1	40.1	54.8	63.8	69.6	77.9	80.5	82.9	72.4	64	53.6	42.7

Figure 8.A-F — STATION: (381939) COLUMBIA_WSFO_AP

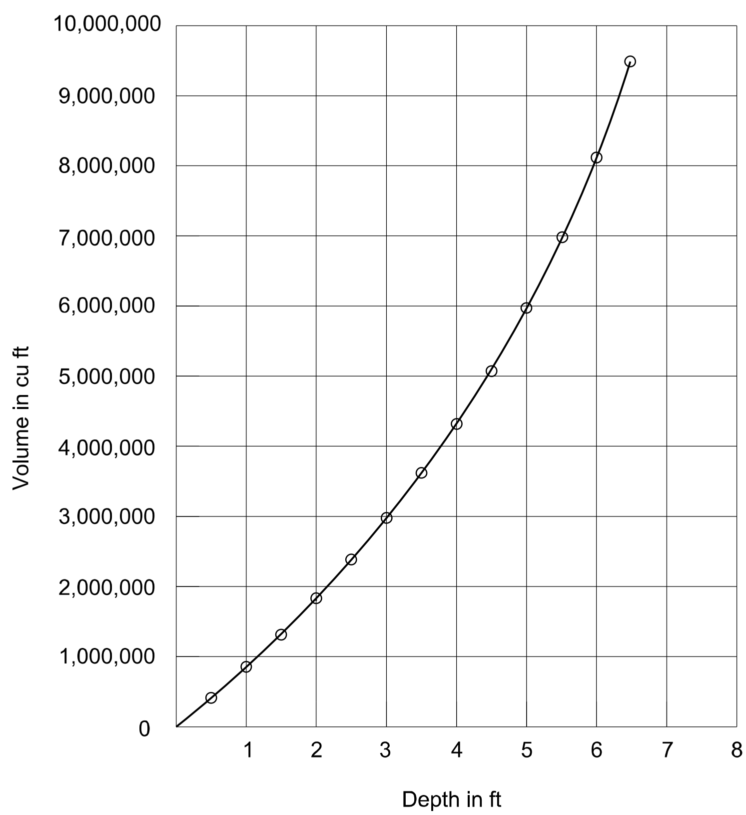

Figure 8.A-G — STORAGE VOLUME

Step 2 Using the topographic map, soils map, aerial photography and field observations, the drainage area was delineated and land use determined. The weighted curve number for the drainage area was then determined Using Equation 8.15. These results are summarized in Figure 8.A-H.

Soil Type	Land Use	Hydrologic Condition	Area (A) in ac	CN	(CN)(A)
A	Woods	Poor	299	45	13,455
B	Woods	Good	346	55	19,030
B	Row Crops	Good	173	78	13,494
C	Woods	Poor	316	77	24,332
C	Meadow	—	255	71	18,105
D	Woods	Fair	329	79	25,991
Totals			1718		114,407

Figure 8.A-H — WEIGHTED CURVE NUMBER

$$CN_{weighted} = \frac{\sum_{i=1}^{n}(CN_i)(A_i)}{\sum_{i=1}^{n}A_i} \quad \text{(Equation 8.15)}$$

CN = 114,407/1718 = 66.6

Find the minimum precipitation that will cause runoff:

$$S = [(1000.0/CN) - 10.0] \quad \text{(Equation 8.16)}$$
$$S = [(1000.0/66.6) - 10.0] = 5.0$$

$$P = 0.2S \quad \text{(Equation 8.17)}$$
$$P = 0.2(5.0) = 1 \text{ in.}$$

Starting with the average precipitation year, 1968, solve for runoff using Equation 8.10 and rainfall over threshold of 1 in. See Figure 8.A-I.

1	2	3	4	5
Month	**Daily Precipitation (in)**	**Q (in)**	**Volume (cu ft)**	**Total Runoff Volume per Month (cu ft)**
January	2.8	0.47	2,928,223	2,928,223
February	0.0	0.00	0	0
March	0.0	0.00	0	0
April	1.9	0.13	795,781	795,781
May	2.1	0.19	1,183,132	1,183,132
June	1.3	0.01	73,162	
	1.5	0.05	313,517	
	1.2	0.01	33,085	419,765
July	2.2	0.22	1,353,679	
	1.5	0.04	238,060	
	1.5	0.05	291,590	
	1.0	0.00	1,589	1,884,918
August	0.0	0.00	0	0
September	1.7	0.08	513,761	513,761
October	2.6	0.38	2,398,432	
	2.0	0.16	1,007,218	3,405,650
November	1.2	0.01	41,277	
	1.5	0.04	278,808	320,085
December		0.00	0	0

where:

- Column 2 is each rainfall event that will produce runoff.
- Column 3 is the computed runoff based on Equation 8.10.
- Column 4 is the volume of rainfall in cu ft over the entire watershed.
- Column 5 is the total runoff volume for each month.

Figure 8.A-I — RUNOFF COMPUTATION FOR 1968

Step 3 Calculate Potential Evapotranspiration (PET) Using Thornthwaite Procedure (Equations 8.6, 8.7 and 8.8). See Figure 8.A-J.

1	2	3	4	5	6	7
Month	**Mean Temp (^oC) T_a**	**I $(T_a/5)^{1.5}$**	**PET (mm/month)**	**Correction Factor**	**PET (mm/month)**	**PET (in/month)**
January	5.1	1.02	7.1	0.84	6.0	0.3
February	4.5	0.85	5.8	0.91	5.3	0.2
March	12.7	4.03	36.3	1.00	36.3	1.4
April	17.7	6.64	65.3	1.08	70.6	2.8
May	20.9	8.54	87.9	1.16	101.9	4.1
June	25.5	11.52	125.1	1.20	150.1	5.9
July	26.9	12.51	137.9	1.19	164.1	6.4
August	28.3	13.45	150.2	1.13	169.7	6.7
September	22.4	9.51	99.8	1.03	102.8	4.0
October	17.8	6.70	66.1	0.95	62.8	2.5
November	12.0	3.72	32.9	0.87	28.7	1.1
December	5.9	1.30	9.5	0.82	7.8	0.3

I = 79.79
a = 1.77

Figure 8.A-J — POTENTIAL EVAPOTRANSPIRATION FOR 1968

where:

- Column 2 is the mean monthly temperature, T_a, converted to °C.
- Column 3 is the intermediate computation $(T_a/5)^{1.5}$ for computing the monthly heat index, I, where I is computed by Equation 8.8.
- Column 4 is PET computed by Equation 8.6 and "a" is computed by Equation 8.7:

$$a = 0.49 + 0.0179(I) - 0.0000771(I)^2 + 0.000000675(I)^3$$

$$a = 0.49 + 0.0179(79.79) - 0.0000771(79.79)^2 + 0.000000675(79.79)^3 = 1.77$$

$$PET = 16\left(\frac{10T_a}{I}\right)^a$$

$$PET = 16\left(\frac{(10)(5.1°C)}{79.79}\right)^{1.77} = 7.1 \text{ mm/month}$$

- Column 5 is the correction factor for latitude interpolated between 30 degrees and 40 degrees.

- Column 6 is PET modified by the correction factor:

$$\text{PET} = (7.1\ \text{mm/month})\ (0.84) = 6.0\ \text{mm/month}$$

Step 4 Groundwater inflow and outflow were summarized in Step 1.

Step 5 Compute water budget. See Figure 8.A-K. In this example, the inflow is computed in terms of volume, then converted to depth in the wetlands based on the depth-volume graph. Computations in this example start with the pond empty. If the user knows the level from the previous month, it should be the starting point.

1	2	3	4	5	6	7	8	9
Month	**Runoff Volume (cu ft)**	**Base Flow (cu ft)**	**Total Volume (cu ft)**	**Depth (ft)**	**PET (ft)**	**Ground-water Outflow (ft)**	**Depth (ft)**	**Total Volume (cu ft)**
January	2,928,223	185,589	3,113,812	3.18	0.03	0.69	2.46	2,188,514
February	0	185,589	2,374,103	2.62	0.03	0.69	1.90	1,557,065
March	0	185,589	1,742,654	2.07	0.13	0.69	1.25	934,832
April	795,781	185,589	1,916,202	2.23	0.23	0.69	1.31	971,872
May	1,183,132	185,589	2,340,593	2.59	0.33	0.69	1.57	1,207,602
June	419,765	185,589	1,812,956	2.13	0.49	0.69	0.95	670,890
July	1,884,918	185,589	2,741,397	2.89	0.52	0.69	1.68	1,313,814
August	0	185,589	1,499,403	1.84	0.56	0.69	0.59	402,040
September	513,761	185,589	1,101,390	1.44	0.33	0.69	0.42	277,289
October	3,405,650	185,589	3,868,528	3.67	0.20	0.69	2.78	2,599,452
November	320,085	185,589	3,105,126	3.15	0.10	0.69	2.36	2,091,835
December	0	185,589	2,277,424	2.53	0.03	0.69	1.81	1,466,530

Figure 8.A-K — WATER BUDGET COMPUTATION FOR 1968

where:

- Column 2 is the runoff computed in Figure 8.A-I.

- Column 3 is the base flow converted to cu ft per month:

$$\text{Base flow} = \left(\frac{0.07062\ \text{cu ft}}{\text{second}}\right)\left(\frac{3600\ \text{seconds}}{\text{hour}}\right)\left(\frac{24\ \text{hours}}{\text{day}}\right)\left(\frac{365\ \text{days}}{\text{year}}\right)\left(\frac{1\ \text{year}}{12\ \text{months}}\right) = 185{,}589\ \text{cu ft / month}$$

- Column 4 is the total volume, which is equal to the volume remaining from the previous month plus the runoff and the base flow for the current month:

$$V = 0.0 + 2{,}928{,}223 \text{ cu ft} + 185{,}589 \text{ cu ft} = 3{,}113{,}812 \text{ cu ft}$$

- Column 5 is the depth for that volume based on the depth volume relationship in Figure 8.A-G.

- Column 6 is the PET from Figure 8.A-J.

- Column 7 is the groundwater flow or permeability expressed as depth in ft per month:

$$K = \left[\frac{3.15\times10^{-6}\text{ in}}{\text{second}}\right]\left[\frac{1\text{ ft}}{12\text{ in}}\right]\left[\frac{3600\text{ seconds}}{\text{hour}}\right]\left[\frac{24\text{ hours}}{\text{day}}\right]\left[\frac{365\text{ days}}{\text{year}}\right]\left[\frac{1\text{ year}}{12\text{ months}}\right] = 0.69\text{ ft/month}$$

- Column 8 is the total depth of water remaining in the wetland basin at the end of the month computed as Column 8 = Column 5 – (Column 6 + Column 7) or inputs minus outputs:

$$\text{Depth} = 3.18\text{ ft} - (0.03\text{ ft} + 0.69\text{ ft}) = 2.46\text{ ft}$$

  When this volume is computed as negative, it is assumed to be equal to 0.0 ft depth. When it is greater than the top of the weir or, in this case, greater than 3.3 ft, it is assumed that the flow will pass over the weir and the depth will be 3.3 ft.

- Column 9 is the volume of water remaining at the end of the month corresponding to the depth in Column 8.

  Plot water budget for 1968. See Figure 8.A-L.

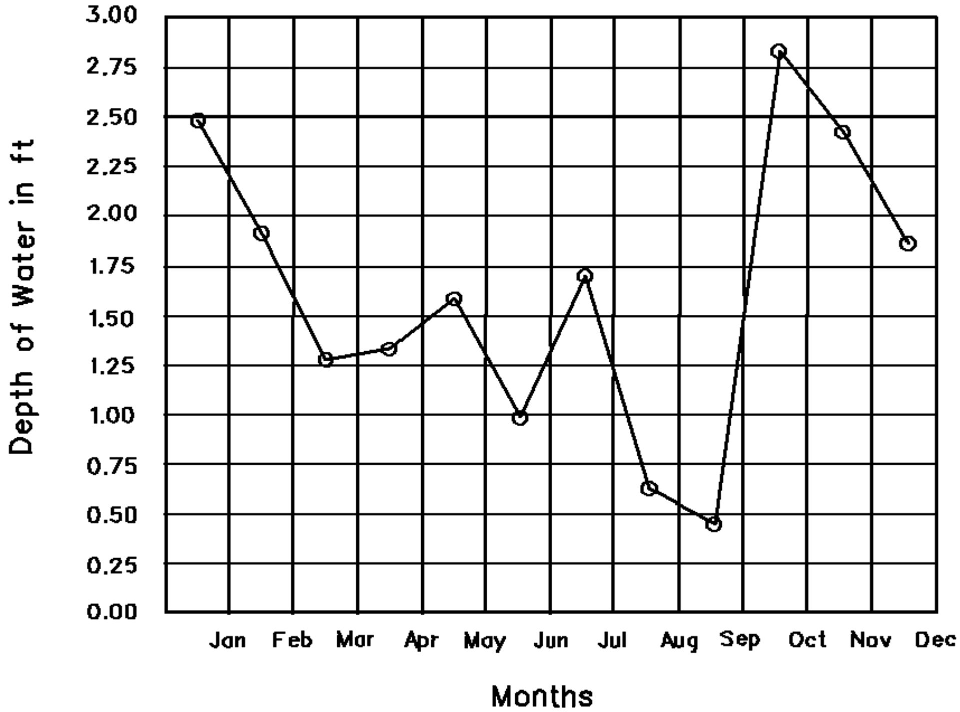

Figure 8.A-L — WATER BUDGET FOR 1968

Repeat the process for the wettest year and the driest year starting with the year 1964, the wettest year. See Figures 8.A-M through 8.A-T. Compute the runoff for the year 1964, remembering that the minimum daily precipitation for runoff to occur is one inch.

1	2	3	4	5
Month	**Daily Precipitation (in)**	**Q (in)**	**Volume (cu ft)**	**Total Runoff Volume per Month (cu ft)**
January	1.38	0.03	165,498	
	1.38	0.03	165,498	330,996
February	1.45	0.04	226,408	226,408
March	1.20	0.01	46,574	
	1.38	0.03	165,498	
	1.71	0.09	541,832	753,904
April	1.78	0.10	648,150	648,150
May	2.05	0.18	1,128,366	1,128,366
June	0.00	0.00	0	0
July	1.13	0.00	19,385	
	1.04	0.00	1,589	
	1.71	0.09	541,868	
	1.52	0.05	300,276	863,118
August	2.49	0.34	2,113,586	
	1.41	0.03	189,509	
	4.20	1.24	7,757,748	10,060,843
September	2.83	0.49	3,041,003	
	3.56	0.86	5,376,195	8,417,198
October	1.27	0.01	84,885	
	2.56	0.37	2,295,115	
	4.09	1.18	7,330,391	
	2.02	0.17	1,067,104	10,777,495
November	0.00	0.00	0	0
December	2.86	0.50	3,120,839	3,120,839

Figure 8.A-M — RUNOFF COMPUTATION FOR 1964

1	2	3	4	5	6	7
Month	**Mean Temp (°C) T_a**	**$(T_a/5)^{1.5}$**	**PET (mm/month)**	**Correction Factor**	**PET (mm/month)**	**PET (in/month)**
January	6.7	1.56	11.0	0.84	9.3	0.4
February	6.5	1.48	10.4	0.91	9.5	0.4
March	12.7	4.03	35.0	1.00	35.0	1.4
April	17.9	6.77	65.6	1.08	70.8	2.8
May	22.4	9.51	99.1	1.16	115.0	4.5
June	26.9	12.51	138.2	1.20	165.8	6.5
July	26.0	11.86	129.5	1.19	154.1	6.1
August	25.8	11.71	127.5	1.13	144.1	5.7
September	23.2	10.01	105.4	1.03	108.6	4.3
October	15.1	5.23	47.9	0.95	45.5	1.8
November	14.6	4.97	45.1	0.87	39.2	1.5
December	9.9	2.78	22.3	0.82	18.3	0.7

I = 82.41
a = 1.82

Figure 8.A-N — POTENTIAL EVAPOTRANSPIRATION FOR 1964

1	2	3	4	5	6	7	8	9
Month	**Runoff Volume (cu ft)**	**Base Flow (cu ft)**	**Total Volume (cu ft)**	**Depth (ft)**	**PET (ft)**	**Ground Water Outflow (ft)**	**Depth (ft)**	**Total Volume (cu ft)**
January	330,996	185,589	516,585	0.75	0.03	0.69	0.03	41,983
February	226,408	185,589	453,980	0.69	0.03	0.69	0	0
March	753,904	185,589	939,493	1.28	0.12	0.69	0.47	308,009
April	648,150	185,589	1,141,748	1.48	0.23	0.69	0.56	378,417
May	1,128,366	185,589	1,692,372	2.03	0.38	0.69	0.96	676,328
June	0	185,589	861,917	1.18	0.54	0.69	0	0
July	863,118	185,589	1,048,707	1.38	0.51	0.69	0.18	134,390
August	10,060,843	185,589	10,380,822	6.99	0.48	0.69	3.30	3,273,767
September	8,417,198	185,589	11,876,554	7.58	0.36	0.69	3.30	3,273,767
October	10,777,495	185,589	14,236,851	8.46	0.15	0.69	3.30	3,273,767
November	0	185,589	3,459,356	3.41	0.13	0.69	2.59	2,351,010
December	3,120,839	185,589	5,657,438	4.76	0.06	0.69	3.30	3,273,767

Figure 8.A-O — WATER BUDGET COMPUTATION FOR 1964

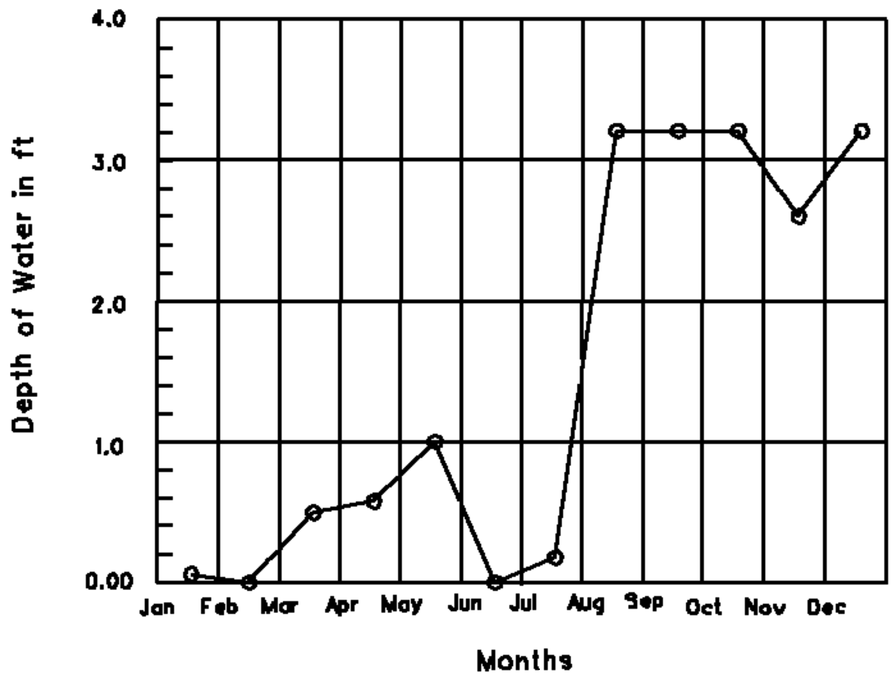

Figure 8.A-P — WATER BUDGET FOR 1964

Repeat process for driest year, 1954.

1	2	3	4	5
Month	**Daily Precipitation (in)**	***Q* (in)**	**Volume (cu ft)**	**Total Runoff Volume per Month (cu ft)**
January	0.0	0.00	0	0
February	1.4	0.04	218,039	218,039
March	0.0	0.00	0	0
April	0.0	0.00	0	0
May	1.3	0.02	77,753	77,753
June	0.0	0.00	0	0
July	1.1	0.00	3,813	3,813
August	2.5	0.34	2,093,742	
	1.4	0.04	226,408	2,320,150
September	1.2	0.01	50,281	50,281
October	0.0	0.00	0	0
November	0.0	0.00	0	0
December	0.0	0.00	0	0

Figure 8.A-Q — RUNOFF COMPUTATION FOR 1954

1	2	3	4	5	6	7
Month	**Mean Temp (^oC) T_a**	**$(T_a/5)^{1.5}$**	**PET (mm/month)**	**Correction Factor**	**PET (mm/month)**	**PET (mm/month)**
January	8.5	2.22	15.1	0.84	12.7	0.5
February	11.3	3.40	26.1	0.91	23.7	0.9
March	12.5	3.95	31.7	1.00	31.7	1.2
April	19.3	7.58	72.9	1.08	78.8	3.1
May	19.2	7.52	72.2	1.16	83.8	3.3
June	26.6	12.27	135.0	1.20	162.1	6.4
July	28.8	13.82	157.3	1.19	187.2	7.4
August	28.4	13.54	153.1	1.13	173.0	6.8
September	25.6	11.59	125.5	1.03	129.2	5.1
October	18.5	7.12	67.2	0.95	63.9	2.5
November	10.2	2.91	21.4	0.87	18.7	0.7
December	7.0	1.66	10.4	0.82	8.5	0.3

I = 87.58
a = 1.92

Figure 8.A-R — POTENTIAL EVAPOTRANSPIRATION FOR 1954

1	2	3	4	5	6	7	8	9
Month	**Runoff Volume (cu ft)**	**Base Flow (cu ft)**	**Total Volume (cu ft)**	**Depth (ft)**	**PET (ft)**	**Ground Water Outflow (ft)**	**Depth (ft)**	**Total Volume (cu ft)**
January	0	185,589	185,589	0.30	0.03	0.69	0	0
February	218,039	185,589	403,628	0.59	0.07	0.69	0	0
March	0	185,589	185,589	0.30	0.10	0.69	0	0
April	0	185,589	185,589	0.30	0.26	0.69	0	0
May	77,753	185,589	263,342	0.39	0.26	0.69	0	0
June	0	185,589	185,589	0.30	0.52	0.69	0	0
July	3,813	185,589	189,402	0.30	0.62	0.69	0	0
August	2,320,150	185,589	2,505,739	2.72	0.56	0.69	1.47	1,109,829
September	50,281	185,589	1,345,699	1.71	0.43	0.69	0.59	390,175
October	0	185,589	575,764	0.82	0.20	0.69	0	0
November	0	185,589	185,589	0.30	0.07	0.69	0	0
December	0	185,589	185,589	0.30	0.03	0.69	0	0

Figure 8.A-S — WATER BUDGET COMPUTATION FOR 1954

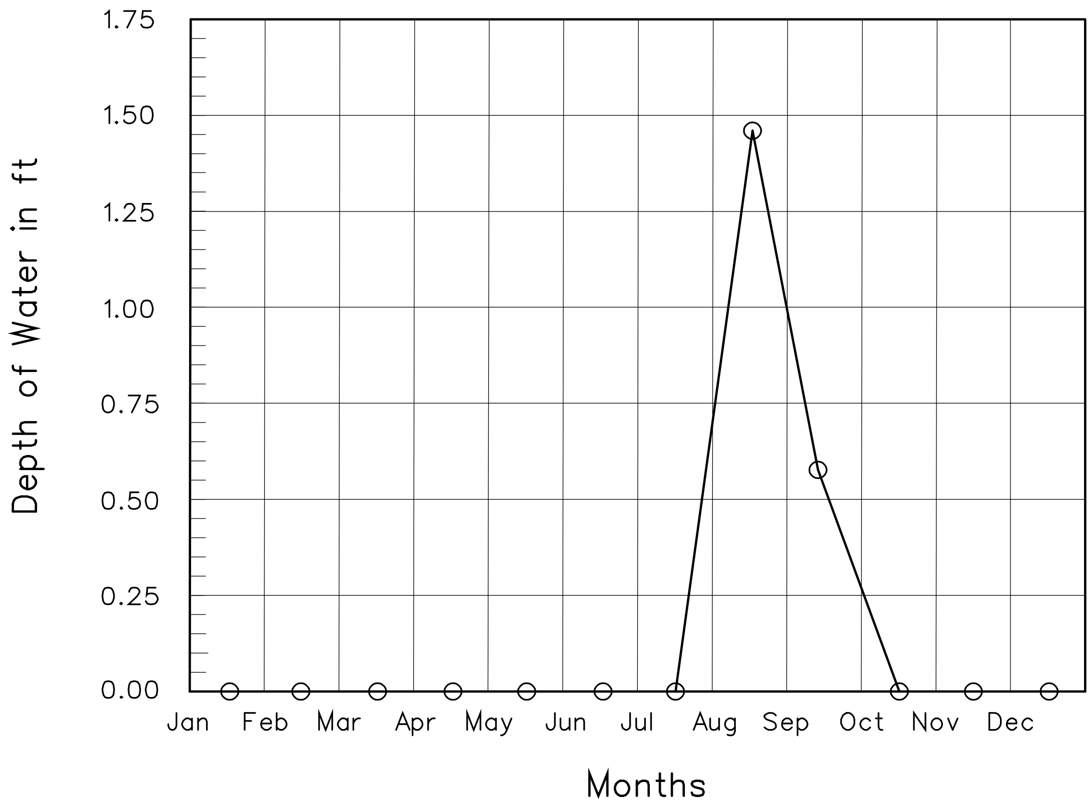

Figure 8.A-T — WATER BUDGET FOR 1954

This example includes base flow to show how it should be computed. In most cases, the accuracy associated with base flow determination will probably not be sufficient to include it in the computations. Therefore, a more conservative estimate of water budget would be computed by assuming no base flow. If hourly rainfall is available, it would be more accurate to compute the water budget on a rainfall event than assuming that the daily rainfall record represents the rainfall event.

When the water budgets are computed, the results should be provided to the Wetland Specialist, who will determine if there is sufficient water and sufficient drawdown at the appropriate times of the year to support the proposed vegetation in the wetland. Because of the uncertainties in the analysis and variability of climatic conditions, the weir must be adjustable so that the water level can be raised or lowered at the appropriate times of the year to meet the requirements of the vegetation.