Chapter 20

WATER CONTROL

Introduction

This chapter discusses site conditions that need dewatering and the extent and basic requirements for construction dewatering. A more comprehensive discussion of technical requirements and methods for constructing dewatering facilities is available in the Reclamation *Ground Water Manual*. The subjects that are discussed include:

- Site review
- Site investigations
- Data collection
- Data interpretation, evaluation, and presentation
- Specifications paragraphs
- Construction considerations
- Supervision and oversight
- Documentation of results (final construction report)

Water control is lumped into two categories—dewatering and unwatering. Water control is the removal or control of groundwater or seepage from below the surface (dewatering) or the removal or control of ponded or flowing surface water by ditches, surface drains, or sumps (unwatering). Excavation of materials or construction near or below the water table or near surface water bodies usually requires control of the groundwater or seepage. Control may involve isolation with cutoffs, stabilization by freezing, grouting, or other methods, or by a combination of methods. Control of groundwater and seepage usually involves installation and operation of wells or drains. A key operation in most water control in unstable materials is the removal of water from below the ground surface in advance of excavation and maintaining the water level at a suitable depth below the working surface. These steps permit construction "in the dry," unhampered by the adverse effects of water.

Understanding what factors control water is critical for ensuring short-term stability during construction of any facility and for the long-term stability of any structure. This chapter discusses what should be considered. If water is considered a potential problem, any field investigation must obtain information on the site's various potential water sources including seasonal precipitation and runoff periods and the identification and understanding of the water bearing zones within a site. This means not only identifying and determining the depths and extent of the various water bearing zones and their water surfaces but also understanding the formation hydraulic parameters (porosity, permeability, and, when necessary, storage).

Figure 20-1 illustrates the importance of understanding the site hydraulic parameters in selecting the appropriate dewatering method. Using the wrong method for the site materials can result in a totally ineffective dewatering system. Figure 20-1 can be used to assess what is the appropriate dewatering method based on the site materials.

In excavations in rock, cemented granular materials, clays, and other stable materials, water removal or unwatering may be by draining to sumps and using surface pumps concurrently with or following completion of the excavation. Subsurface cutoffs such as sheet piling and slurry walls in soil or soft rock and grouting in rock are also used to control ground and surface water and for ground support. Cutoffs are seldom 100-percent effective, and supplementary dewatering or unwatering is usually required. Soils are frozen for short periods such as for a

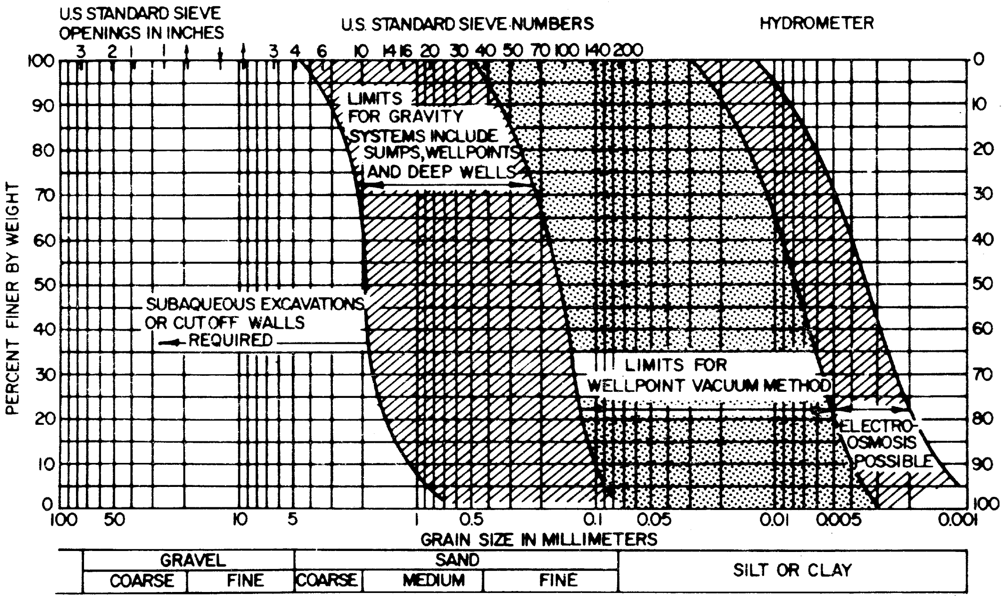

Figure 20-1.—Limits of dewatering methods for different materials.

temporary excavation, especially in clayey or silty soils that have low permeability and are difficult to drain.

Unwatering methods are commonly used in soils that have high porosity but low permeabilities (clayey or silty soils), bedrock that has solution cavities, and lava tubes that carry large volumes of water in isolated areas. Unwatering methods are commonly used to control surface water.

Unwatering usually is performed in conjunction with dewatering to ensure control of surface water and to permit dewatering to proceed unaffected by recharge or flooding from nearby surface water. Failure to properly remove or control water during unwatering or dewatering may result in:

- Unstable natural or excavated slopes
- Unstable, unworkable, or unsuitable subgrade
- Boils, springs, blowouts, or seeps on slopes or in the subgrade
- Flooding of excavations or structures
- Uplift of constructed features such as concrete slabs
- Dilution, corrosion, or other adverse effects on concrete, metals, or other construction materials
- Instability of nearby structures
- Draining surrounding surface water and groundwater

- Instability of cutoff facilities such as cofferdams
- Loss of fines from the foundation
- Safety problems
- Delays in construction
- Increased construction costs

Water control may vary widely in scope, magnitude, and difficulty. Some controlling factors related to the constructed feature include footprint, foundation depth, and construction time. Factors related to site conditions are:

- Subsurface geology including general material types; bedding, attitudes and lateral extent of bedding; and attitudes, continuity, and apertures of fractures
- Subsurface hydraulic conditions including permeabilities and thicknesses of different materials, groundwater occurrence, and levels
- Recharge conditions including proximity to surface water bodies and precipitation
- Other facilities including cofferdams and site access

Conditions that may indicate the need for dewatering and the possibility for difficult dewatering include:

- Site location adjacent to a large body of surface water, a stream, a marshy area, or an area subject to flooding
- An excavation significantly below the water table

- Complex foundation geology
- An artesian zone immediately below grade
- Existing structures or facilities
- Existing use of groundwater
- Poor quality groundwater
- Presence of hazardous materials
- Thick zones of saturated, low-strength materials such as silt or soft clay, especially under artesian conditions
- Presence of cofferdams or other similar features for which dewatering is needed for stability
- Conditions where failure of dewatering facilities could result in catastrophic failure of protective or other features and a hazard to life or property

Sites requiring groundwater or seepage control for construction or proper operation of a facility should be identified as early in the planning or design process as possible.

Exploration Program

Investigations for water control should be part of the general exploration and design data collection program. Advantages of conducting investigations together include:

- Maximizing the use of design data collection and lowering exploration costs
- Providing dewatering data early in the program
- Using field personnel efficiently

Water control investigations generally cannot be established in detail until some reconnaissance level drilling has been done and general subsurface geologic and hydrologic conditions are determined. General surface conditions including topography and surface hydrology should be known. A specialist should be consulted as early in the program as possible to maximize the benefits of the obtained data.

Design Data Requirements, Responsibilities, and Methods of Collection and Presentation

Adequate surface and subsurface data are essential to the proper design, installation, and operation of water control facilities. The amount of data required for water control facilities design may equal or exceed the foundation data required for design of the structure. Water control facilities may be designed in-house or by the contractor; but investigations may be extensive, complex, time consuming, and beyond the capability of a contractor to accomplish in the bidding period. An in-house design is generally better because the time is usually available to do the job right, the designer has control over the design data, responsibility for the water control design is clear to the owner and the contractor, and the contractor can bid the water control installation more accurately.

Design data for water control facilities should be obtained regardless of who is ultimately responsible for the design.

The extent and level of data should be appropriate for the anticipated water control requirements and facilities. All subsurface investigations should be sufficiently detailed to determine the groundwater conditions, including the depth of the vadose zone and the various potentiometric water surfaces; and the investigations should provide at least enough data to estimate the permeability of the soil or rock. Crude soil permeabilities can be estimated from blow counts and the visual or laboratory soil classification. Permeability tests should be considered in any exploration program. If aquifer tests are required, the test wells should approximate the size and capacity of anticipated dewatering wells. Facilities should be preserved and made available to prospective contractors for their testing or use, if appropriate.

If the contractor is responsible for the dewatering design, all field design data should be included in the construction specifications. Data include details of drilling and completion of exploratory drill holes, wells, piezometers, and other installations as well as test data. Data should be as concise as possible and clearly show the history, sequence, and location of all exploration. Design data for water control facilities should be obtained concurrently with feature design data if possible. Specialists should be consulted when preparing design data programs, especially programs for foundation drilling and aquifer testing. Water control data are an essential part of the design data package and must be given the required priority in funds, time, and personnel to minimize problems such as construction delays and claims. Where dewatering may have impacts on existing adjacent structures, wells, facilities, or water resources, a study of the area surrounding the site may be necessary to determine and document impacts. In addition to data involving the constructed feature such as a structure layout, excavation depth, and time to construct, other information is required on site conditions such as:

Surface Data

- Site and surrounding topography at an appropriate scale and contour interval
- Cultural features on and off site
- Site and surrounding surface geology with descriptions of materials
- Site and adjacent surface water features such as lakes, streams, swamps, bogs, and marshes
- Plan map of all data points, including locations of drill holes, test holes, piezometers, observation wells, test wells, and overlays on the plan of the proposed feature

Surface information should include data on soil erosion or resistance or how erosion relates to runoff or the potential recharge of the groundwater system. Soil infiltration data from Natural Resource Conservation Service mapping should be included if available.

Subsurface Data

Subsurface data should include representative permeabilities, a real distribution of permeabilities, location and potential recharge sources or barriers, and anticipated seasonal changes in the groundwater system. When a project has a relatively high soil or rock permeability and the permeable formation extends laterally over a large area, storage (storativity, effective porosity) of the aquifer requires evaluation. Specific data that may be necessary include:

- General geology of the site and surrounding area including geologic cross sections that show vertical and lateral variations in materials

- Logs of drill holes, test holes, and piezometers showing depths and thicknesses of materials, descriptions of materials, and results of testing

- Results of material sampling including depths, descriptions, mechanical analyses, and hydrometer analyses

- Geophysical logs

- Aquifer or permeability test results including yields and drawdown with time and static water levels

- Layout of test holes and depths and designs of wells and piezometers

- Water quality analyses

Other Data

- Climatic data for the nearest station including daily temperature and precipitation and details on the occurrence of severe storms

- Streamflow and elevation, lake or reservoir depth, elevation, and other similar data

- Groundwater levels for monitored observation wells, piezometers, test wells, drill holes, and pits

- If a nearby surface water body and the groundwater are connected, continuous monitoring of both features for a typical hydrologic cycle

Presentation of Data

The presentation of dewatering data may differ from the presentation of conventional geologic data because water control data are subject to a variety of quantitative interpretations and because water levels, flow, and water quality vary with time.

Because of the potential for different interpretations, most dewatering data such as those from aquifer tests and packer tests are presented as observed field data and as interpretations. A complete description of the site, subsurface conditions, and test facilities should be given along with the data (figures 20-2 and 20-3).

Where time related data are presented, the information should be in a form that will ensure maximum recognition and proper interpretation. Hydrographs that plot time versus water levels mean a lot more than a table of readings.

Monitoring

Water control activities must be monitored during construction and, in some cases, up to a year or more before and following completion of the facility. Details of the monitoring program including design and layout of the system, the responsibilities for installing the system, and monitoring and maintaining records must be included in the specifications and construction considerations to ensure adequate reliable data and inform construction personnel of monitoring requirements.

PUMPED WELL WELL NO. 269			OBSERVATION WELL DH-270 RADIUS 30 FEET		OBSERVATION WELL DH-271 RADIUS 99 FEET		OBSERVATION WELL DH-100 RADIUS 100 FEET				OBSERVATION WELL DH-102 RADIUS 87 FEET			
							DEEP PIEZOMETER *		SHALLOW PIEZOMETER		DEEP PIEZOMETER		SHALLOW PIEZOMETER	
ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)	DISCHARGE (GAL./MIN.)	ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)	ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)	ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)	ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)	ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)	ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.17	0.93	-	1	0.07	1	0	41	+0.57	41	0.13	36	0.03	36	0.25
0.50	1.02	-	1.5	0.09	2	0.05	63	+1.09	315	0.11	83	0.03	84	0.22
0.67	1.03	-	4	0.10	3	0.05	151	+1.36	379	0.18	146	0.04	147	0.24
0.83	1.07	-	5	0.07	4	0.05	194	+1.37	441	0.19	201	0.05	202	0.24
1	1.09	-	8	0.11	5	0.05	314	+1.42	496	0.16	311	0.10	312	0.38
1.17	1.12	-	10	0.11	7	0.05	378	+1.33	619	0.20	377	0.04	377	0.38
1.33	1.13	170	14	0.11	9	0.05	441	+1.36	731	0.27	402	0.06	402	0.30
1.67	1.05	-	21	0.11+	11	0.09	496	+1.38	859	0.19	439	0.08	439	0.15
1.83	1.01	-	31	0.12	13	0.09	620	+1.33	*976	0.21	491	0.09	491	0.36
2	1.03	-	40	0.11+	15	0.09	731	+1.34			617	0.16	617	0.37
2.33	1.11	-	48	0.13	20	0.09	858	+1.34			738	0.17	739	0.38
2.67	1.10	-	53	0.13	25	0.09	976	+1.43			855	0.11	856	0.36
3	1.08	-	58	0.14	30	0.09	1088	+1.58			979	0.12	979	0.36
3.50	1.09	-	73	0.14+	35	0.09			(Obstruction in pipe at 5.36 feet)		1098	0.15	1099	0.35
4	1.11	-	83	0.15	55	0.15								
5	1.10	170	97	0.16	65	0.10								
6	1.10	-	103	0.17	75	0.15								
7	1.11	-	118	0.19	85	0.15								
8	1.11	-	138	0.20	95	0.15								
9	1.11	-	168	0.18	105	0.15								
10	1.11	175+	171	0.17	123	0.15								
12	1.12	-	183	0.18	138	0.15								
14	1.11	-	231	0.19	153	0.15								
16	1.15	-	250	0.19	168	0.15								
18	1.15	-	265	0.16	183	0.15								
20	1.14	-	318	0.16	198	0.15								
26	1.15	-	378	0.21	213	0.15								
30	1.14	175+	453	0.21	228	0.15								
35	1.15	-	498	0.22	243	0.15								
40	1.13	-	618	0.24	258	0.15								
45	1.14	-	738	0.24	318	0.16								
50	1.15	-	858	0.25	378	0.10								
60	1.15	-	978	0.23	438	0.15								
70	1.17	-	1103	0.23	498	0.23								
80	1.18	-	1118	0.19	741	0.25								
90	1.17	-			853	0.25								
100	1.15	178			980	0.25								
120	1.15	180			1100	0.28								
135	1.15	-			1126	0.29								

* Apparently influenced by discharge water. One small part of flow ponds about 10 feet west of well, and then flows within 8 feet of the well as it flows past on the way to the lake.

* May have been responding. However readings believed to be unreliable, due to obstruction in pipe and behavior of the deep piezometer. No further readings taken.

NOTE: Well located about 30 feet from lake shore.

Figure 20-3.—Aquifer test data.

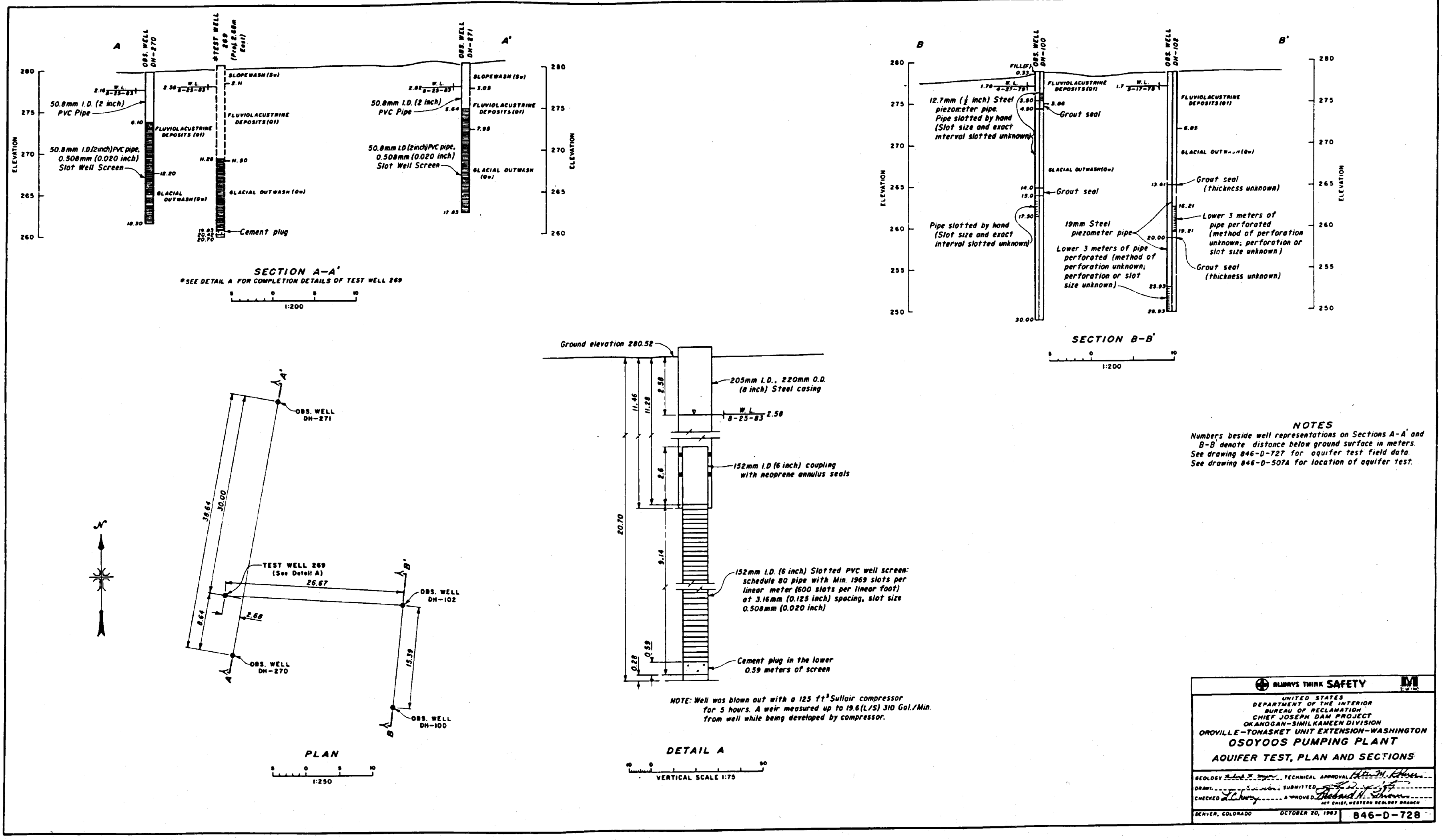

Figure 20-2.—Aquifer test, plan, and sections.

Monitoring is intended to:

- Provide data on base level conditions
- Confirm that the specifications requirements are being met
- Maintain a general data base on conditions and impacts resulting from the dewatering
- Alert personnel to unsuitable, hazardous, or potentially hazardous conditions
- Document conditions in the event of claims or litigation
- Provide background data for a followup analysis in the event of a slope, foundation, or structural failure

Monitoring of water control parameters, activities, and features should include:

- Groundwater levels
- Discharges
- Sediment content of discharges
- Chemical and biologic quality of water discharged
- Horizontal and vertical control on constructed features and natural and excavated slopes
- Levels and sizes of nearby surface water bodies
- Stability of nearby structures

The monitoring facilities may range from a few observation wells to a complex system involving sophisticated equipment and continuous and possibly remote monitoring. The extent, complexity, and capability of water control facilities depend on the size and complexity of the facilities and the hydrologic and geologic conditions and excavation depths.

Groundwater Monitoring

Monitoring during construction should include groundwater levels in excavations, areas surrounding the excavations, and off-site locations. Excavations of any substantial width (other than trenches) and a depth of more than a few feet below the anticipated water level may need groundwater monitoring instrumentation installed directly in the excavation. Excavations underlain at shallow depths by artesian conditions may need to be monitored because of the potential for blowout.

Groundwater Monitoring Locations

Groundwater monitoring instrumentation located within an excavation may interfere with the contractor during construction, but monitoring groundwater levels within an excavation generally justifies inconveniences. Because the most difficult area to dewater is usually the center of the excavation, groundwater monitoring instruments should be located near the center. Special provisions may be necessary to ensure continued groundwater monitoring of the facilities during all stages of the excavation. In some cases, groundwater monitoring instrumentation may be incorporated into the structure. This may require that the monitoring instrument be embedded in concrete such as a wall or pier to permit continuous monitoring and simplify backfill operations.

Water level monitoring instrumentation should be located in areas surrounding the excavation to monitor representative areas and specific problem areas. Groundwater levels in off-site locations should be monitored to maintain a general record of conditions and to document dewatering. Off-site monitoring is especially important in areas where groundwater is widely used, where groundwater levels are crucial to existing activities, or where there might be subsidence or groundwater level decline.

Locations of individual water level monitoring instruments must be based on conditions encountered at the site, construction activities, and the dewatering facilities. Monitoring instrumentation locations generally will have to be selected after other features such as dewatering systems and roads have been located to avoid conflicts and to ensure representative and reliable monitoring. Instrumentation should be installed and functioning long before construction to obtain trends and base level conditions. Existing instrumentation may be used for monitoring; but unless the instrumentation construction and other details are known, instrumentation designed specifically for the conditions of the site should be installed as a part of construction.

Groundwater Monitoring Instrumentation

Instrumentation for monitoring groundwater levels usually consists of several observation wells or piezometers. The type of instrumentation, depth, and riser and hole diameter depends primarily on subsurface conditions, desired operating life, and type of monitoring. The design of the instrumentation should be tailored to the subsurface and data requirements so that measurements are a true indication of in place conditions.

Observation wells intended to monitor general groundwater levels can be used in areas where the foundation material is relatively uniform in depth, there is little or no layering, and groundwater levels do not vary appreciably with depth. Piezometers should be used where layering exists or perching, artesian, or complex conditions are expected.

Observation wells and piezometers usually consist of a section of well screen, perforated pipe, or porous tube isolated in the zone to be monitored and connected to a length of standpipe, riser, or casing extending to the surface. The section of well screen, perforations, or porous tube must be isolated with a watertight grout or bentonite seal, and a watertight riser must be used. The diameter of the screen and standpipe should conform to ASTM D-5092. Water levels are measured directly in the well or piezometer by use of tape or electric sounder (M-scope). Float-type recorders can be used to continuously record water level fluctuations but may require a minimum 4- to 6-inch (10- to 15-cm) diameter casing or standpipe. A wide range of electronic and pneumatic instruments is available for monitoring and recording groundwater levels.

Special types of monitoring wells or piezometers may be necessary if hazardous materials are present.

Monitoring Discharges From Dewatering Systems

The discharge from dewatering facilities such as wells, well point systems, drains, and sump pumps should be monitored to provide a record of the dewatering quantities. Data should include starting and stopping times, instantaneous rates of discharge, changes in rates, combined daily volumes, and, in some cases, water chemistry, turbidity, and biologic content.

Discharge rates can be monitored by flow meters (propeller, pitot tube, and acoustic), free discharge orifices, weirs, flumes, and volumetric (tank-stopwatch) methods. Meters must be calibrated using a volumetric test before flow testing. Measuring devices generally must be accurate within 10 percent.

Sediment content of dewatering facilities including wells, well point systems, and drains should be monitored. Sediment can damage pumping equipment, cause deterioration of water quality in a receiving water body, and create voids in the foundation that result in well collapse and foundation settlement.

Sediment content usually is measured in parts per million by volume of water or in nephelometric turbidity units (NTU) in water taken directly from the discharge. Measurement requires special equipment. If the limits are 50 parts per million or less, a special centrifugal measuring device is required. If the limits are more than 50 parts per million, an Imhoff cone can be used. A turbidity meter typically measures values less than 2,000 NTUs. Values less than 200 NTUs are generally acceptable for discharge. If sediment yield increases rapidly, the facility may need to be shut down to avoid serious damage or contamination.

The chemical and biologic content of water discharged from dewatering systems should be monitored by periodic collection and analysis of samples taken directly from the system discharge. A single representative sample is adequate if there are a number of discharges from the same source. If there is pumping from different sources, multiple samples may be needed. The initial samples should be taken shortly after startup of the dewatering system (or during any test pumping done during exploration) and periodically during operation. Each sample may need biologic and chemical analyses for heavy metals, organics, and pesticides. More frequent sampling and analyses may be made to determine total dissolved solids, conductivity, pH, and sediment content or turbidity.

Monitoring Water and Ground Surfaces and Structures

Well or Piezometer Design.—Most groundwater monitoring for water control investigations is to collect water level information, but some monitoring is to obtain water quality information. All monitoring wells should be constructed according to ASTM D-5092 and constructed for site conditions and purposes. Geologic conditions, available drilling equipment, depth to water, and the frequency of the readings should be factored into the design of a monitoring well. If a monitoring well requires daily or weekly readings, the well may require installation of an automated water level monitoring system. The type and diameter of riser should be based on the intended use of the monitoring well. If monitoring is to continue into construction, protecting the well should be part of the design. Too often, a piezometer or observation well is constructed without any serious attempt to design the well. Typically, monitoring wells are constructed using 1-inch (2.5-cm) diameter PVC risers with a screen slot size of 0.010 inch (0.25 mm) or with or without a 10/20 sand pack. This "low permeability" monitoring well design is appropriate if the well is monitored only for water levels and the adjacent sources of recharge due to precipitation, dewatering, unwatering activities, or other water bodies is not changing rapidly.

All monitoring wells should be completed using the appropriate seals, risers, and openings to allow the water level in the riser or piezometer to respond to the formation rather than to the water within the riser, the screen, or the sand pack. Improper or inadequate removal of cuttings and drill fluids, or too fine a slot or sand pack, can delay the response of groundwater within a riser. Too large openings can result in clogging of the monitoring well and impact the chemistry of the groundwater. A water quality monitoring well in soils or decomposed to intensely weathered bedrock should have a minimum of 2-inch (5-cm) risers with an annular space of at least 2 inches (5 cm). All wells with screen or slots should be developed, especially if the well is being used to obtain water quality samples. Clays and humic materials of colloidal sizes can skew water quality tests.

Ground Surface Monitoring.—The ground surface and other pertinent points should be monitored for settlement during dewatering activities. Use standard surveying methods (at least third order) and temporary benchmarks or other facilities to maintain survey control. Horizontal control is necessary in large or deep excavations that may be susceptible to slope failure. Special instrumentation with alarm warning capability may be necessary if ground failure might endanger life or property.

Water Surface Monitoring.—Nearby surface water bodies, swamps, drains, and other similar features should be monitored, if appropriate, for elevation and discharge changes and environmental changes.

Structural Monitoring.—Nearby structures that may be influenced by settlement or horizontal displacement caused by groundwater withdrawal should be monitored. Both horizontal and vertical measurements should be acquired to detect movement.

Performance Evaluation During Construction

The performance of the water control facilities should be evaluated and documented periodically during construction. This will ensure that the specifications are being met and that unusual or unexpected conditions are properly accommodated. Charts and diagrams such as hydrographs or plots of well or system discharge rates should be prepared at the start of dewatering operations and updated throughout the construction period. An evaluation, along with tables and graphs, should be included in monthly reports to provide essential data for final reports. The evaluation should be coordinated with the design staff to ensure complete understanding of conditions.

Final Reporting

The final construction report should include a section on water control. This section should include a chronology of dewatering and an evaluation of the performance of the facilities as well as contractor compliance with the specifications. Problem areas and unusual events such as pump or slope failures should be documented. Monitoring results, including groundwater levels and discharge rates, should be presented in the form of hydrographs and other similar plots or tabulated data.

Bibliography

Bureau of Reclamation, U.S. Department of the Interior, *Ground Water Manual*, 2nd Edition, 1995.

Cedergren, Harry R., *Seepage, Drainage and Flow Nets*, John Wiley and Sons, Inc., New York, New York, 1967.

Driscoll, Fletcher, G., *Ground Water and Wells*, Johnson Division, St. Paul, Minnesota, 1986.

Joint AEG-ASCE Symposium, *Practical Construction Dewatering*, Baltimore, Maryland, May 16, 1975.

Leonards, G.A., Editor, *Foundation Engineering,* McGraw-Hill Book Co., Inc., New York, New York, 1962.

Powers, J. Patrick, *Construction Dewatering,* John Wiley and Sons, New York, New York, 1981.

U.S. Departments of the Army, the Navy, and the Air Force, *Dewatering and Groundwater Control for Deep Excavations*, TM5-818-5, NAVFAC P-418, AFM 88-5, Chapter 6, April 1971.