SO YOU THINK YOU NEED MORE WATER?

A guide to developing water supplies for small water systems

AMERICAN WATER WORKS ASSOCIATION

PACIFIC NORTHWEST SECTION

OREGON WASHINGTON WESTERN IDAHO

2000

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American Water Works Association
Pacific Northwest Section
Water Resource Committee

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American Water Works Association
Pacific Northwest Section
Water Resource Committee

Chapter I
INTRODUCTION

Purpose

The Pacific Northwest Section of the American Water Works Association Water Resource Committee prepared this handbook to assist small water systems considering new sources of supply. For the purposes of this handbook we consider a "small" water system one with less than 3,000 connections. Smaller water systems are pursuing new supplies in an ever more complex and competitive environment. As this competition for water supply grows, the way a small system plans for new water supply can dramatically affect the system's success.

This handbook:

- Provides approaches for successful water supply development
- Identifies typical issues that should be addressed when pursuing new supplies
- Describes alternative supply strategies

The handbook introduces new concepts such as integrated resource planning and water conservation measures. As we gain additional experience, the appropriate use of these tools will become clearer and this guide should be updated.

Format

This handbook contains step-by-step descriptions of recommended approaches to water supply problems. The appendices list additional sources of information that could be useful to water systems preparing water supply plans.

Handbook Contents

Chapters II through VI present a step-by-step process for addressing common issues that arise when pursuing new supply. **Chapter II** introduces the concept of determining how much water is enough for your system. **Chapter III** describes how to determine the amount of supply needed. **Chapter IV** lays out some traditional and non-traditional options for new supply. **Chapter V** provides some cost examples and assumptions to assist in evaluating supply options. Finally, **Chapter VI** discusses the governmental approval process as it applies to water systems and their supply.

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Chapter II
WATER SUPPLY ADEQUACY AND RELIABILITY
HOW MUCH IS ENOUGH?

Getting Started

There are a number of important factors affecting the planning process for a water supply project. One of the most important decisions is determining the needed supply's capacity and the reliability of future demand projections. In many cases, this decision requires some level of risk analysis and acceptance. Risk acceptance comes in the form of understanding that economic, environmental, and social constraints may place a community in a position that a water supply project may not meet 100 percent of community demands in every future year. While the supply may not meet every year's demands, the community has made this choice based on what is viewed as adequate for their circumstances. Appropriate planning can be initiated and community awareness developed as a method for dealing with shortfall years.

This chapter is intended to serve as a basic primer to utility managers, boards, and city councils, and describes the steps generally taken in determining the level of reliability and, conversely, risks which a community is willing to accept from their proposed water supply. The three components of this chapter provide discussions of water demand projections and the development of adequacy or reliability criteria, definitions of typical community water supply constraints, and the public involvement necessary to develop a community supported decision.

Water Supply Constraints and Projected Demand Relationships

As a community anticipates expansion of their water supply, several constraints will come to bear on the planning and decision process. These constraints can be generally categorized as social, economic/financial, and environmental. While many factors may be involved, projected water demand is the key driver on the intensity of these constraints. Therefore, an accurate demand projection is critical to fully analyze the true magnitude of the constraints. The demand analysis will also be useful in developing criteria by which the adequacy of the supply is measured. Single or multiple criteria can be developed which are used to compare different source alternatives' reliability. Typical criteria are the supply's ability to meet its average annual and peak season demands at different confidence levels. The confidence levels are directly related to the community's constraint analysis and acceptance.

Water Supply Constraints

A. Social

The social acceptability of the reliability of the water supply is an amalgamation of the demographics of the community, its cultural biases, the perceived carrying capacity of the service area, as well as economic and environmental considerations. In the most basic analysis, the social constraint can be viewed as perspectives, which are residentially and industrially based and, in some cases, driven by agricultural perspectives. The residential component will generally have the largest range of supply acceptability, whereas the industrial component will generally have the narrowest tolerance for variability in the quantity of water supply. It is important to understand the cultural and operating characteristics of each of these customer classes within the community in assessing the magnitude of social constraint.

B. Economic/Financial

The economic and financial impacts of a proposed water supply project are measured somewhat differently yet generally result in a funding or financial constraint. An economic analysis should produce a comparison of supply alternatives expressed as a cost benefit ratio. This will allow the community to understand the cost per unit of the projects or cost efficiency. The economic analysis should include design, construction, mitigation costs, as well as the effect on the demand projections by conservation programs and price elasticity in rates needed to support the water supply alternatives.

The financial analysis will provide a summary of the costs for each alternative evaluated. It is important to understand that the most cost efficient alternative may not be the most financially viable alternative for the community, although that is the desired outcome. For instance, the most cost efficient system may be larger and more costly than a smaller less efficient system. The community's ability or willingness to pay for the project will determine the financial viability of an alternative. Factors to consider are community demographics, type and health of economy, and current and projected rates.

C. Environmental

Evaluation of social environmental values must be included in analyzing the need for new water resources. Decision-makers must weigh these values with economic factors subjectively to reach a choice. However, significant public input will be required in fully exploring this constraint. When supply alternatives are developed, it is necessary to carefully consider the ecological impact on streams and adjacent areas to try to develop a plan that will have minimum detrimental effect. A partial list of environmental consequences of water resources projects might include:

- Degradation of downstream channels or coastal beaches by loss of sediment trapped in a reservoir
- Loss of unique geological, historical, archeological, or scenic sites
- Impact on spawning beds for migratory fish preventing their reproduction
- Change in stream water temperatures
- Change in aquatic species in a stream
- Release of reservoir water which may be high in dissolved salts or low in oxygen, resulting in impacts to aquatic species
- Impact to wetlands, decreasing the opportunity for survival of aquatic or amphibious animals or water fowl
- Changes in water quality as a result of drainage changes
- Creation of a barrier to normal migration routes of land animals
- Altering aquatic species by increased turbidity by man-induced erosion
- Damage to fish by passage through pumps or turbines or over spillways
- Damage to stream bank vegetation
- The effect on other wells caused by pumping from a new well or well field
- The potential reduction in surface water available for instream uses by capture of groundwater that otherwise would discharge to surface water
- Possible change in ordinary groundwater flow direction in areas local to a well or well field

- Pumping from wells could cause the spread of contamination if contaminated properties are within the area influenced by pumping

There are many more items that could be added to this list, and there are subtle effects that will be identified as a project analysis proceeds. A clear distinction should be made between damage that is temporary (i.e. related to construction operations or clearing) and effects that are long-term, irreversible, or can be reasonably mitigated.

Public Involvement

The public involvement effort of a water supply adequacy program will ensure that sufficient public education, input, and involvement are achieved during the process of formulating defensible supply adequacy decisions. In most cases, public involvement is specifically mandated by national and/or state environmental impact reviews and will depend upon the type of projects anticipated for development. A relatively simple environmental checklist may be employed to satisfy this requirement or a full environmental impact statement could be necessary. The first step is to meet with federal and/or state officials, and after they have reviewed an action plan, to scope the level of environmental review effort that they deem necessary to satisfy this law.

The development and refinement of a comprehensive communications plan, including identification of key audiences and strategies, is an important part of the public involvement process. The utility will need to identify the most likely local media outlets to provide coverage and placement of general informational stories related to the background of the water supply adequacy program and reasons for the project. Press releases should be distributed, as well as coordinating media background briefings with key reporters of the local area. Utility personnel must also be prepared to develop effective responses to media inquiries.

As work proceeds in evaluating the water supply adequacy issues, a process must exist to provide ongoing media coordination and strategy development related to press releases to the local news media.

This strategy, if implemented successfully, will:

- Engage the public quickly and effectively
- Maintain and strengthen essential public support
- Improve the political support necessary for program completion
- Effectively respond to concerns or criticism and provide answers that support the project
- Build a credible working relationship with the media

A. Board/Council

Presentations must be made to elected officials and key staff throughout the process of making supply adequacy decisions. Initial meetings are usually made to the elected body as a whole, including briefings and regular progress updates. However, additional meetings (individually or with small groups) are an excellent way to provide public officials a forum to freely express any concerns they may have and to ask additional questions. These meetings also serve to provide feedback on the presentation and the message being conveyed. Adjustments can be made to the program accordingly to reinforce any areas that may be weak.

The ability to respond to changing circumstances and emerging issues with midcourse adjustments and new tactics will be an important factor in keeping the effort on track.

B. Citizens Advisory Committees

The purpose of a Citizens Advisory Committee (CAC) is to bring interested citizens together to assist in the definition of the water supply adequacy program. Members are generally recruited through solicitations at public meetings and also through media outreach. When selecting members, it is important to identify stakeholders and to ensure that they are given the opportunity to be represented on the CAC. If key players are left out of the process, they may oppose the project for lack of understanding.

Once the CAC is formed, orientation and guidance should be provided to the CAC. The meetings should be well designed, planned, coordinated, and managed. In order to reach out to a broader audience, subcommittees or focus groups may be formed to address issues identified by the CAC in more depth and detail. These subcommittees or focus groups would be assigned tasks to accomplish and would be expected to report back to the CAC.

An additional step that may be implemented through the CAC is the development of a survey. The purpose of the survey is to solicit and receive input from the general public. This is an excellent tool to determine public sentiment regarding the issues identified by the CAC, a subcommittee, or focus group.

C. Workshops

The purpose of the workshop format is to disseminate information and possibly to recruit members for the CAC. The workshops should be held in several different geographical locations around the community to encourage participation. Strategies, formats, agendas, logistical support, and publicity for the workshops should be developed. The development of presentational messages and audio-visual aids should also be considered.

Following a formal presentation, a question and answer period should be conducted. Next, a solicitation of comments, ideas, and suggestions should be made, followed by an exit poll interview. The information collected from these workshops should be used in the overall planning of the public information activities.

Summary

Water resource management for a diverse and growing set of demands will continue a trend towards more complex solutions. These solutions will require both traditional and emerging concepts. Understanding the dynamics and components of the process will allow communities to successfully navigate a course to a successful project. Community based risk assessment and acceptance is an important aspect of the process.

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Chapter III
HOW MUCH WATER DO YOU NEED?

Getting Started

Before identifying new sources, the first question to be answered is how much water is required. The issues surrounding water supply requirements are discussed in this chapter. Once supply requirements have been established, many other questions will also need to be addressed:

- What are alternative sources for that amount of water?
- Can you obtain water rights?
- What are the water quality and associated treatment requirements for each alternative?
- How can those sources be protected?
- How much will they cost to develop?
- Can your sources be expanded?

This chapter addresses the first question. **Chapters IV and V** discuss the other questions. This chapter and the following two chapters lay the foundation for negotiating the agency approval process described in **Chapter VI**.

To successfully obtain new water supply sources, you must carefully document exactly how much water is needed to serve your system. Following is a four-step process to help you meet agency requirements.

1. Determining your system's current capacity
2. Documenting your current demands
3. Projecting future demands
4. Calculating your new supply needs

The need for an additional water source may be a true need or a perceived need. For instance, in a system with pressure problems or with high per capita consumption, it may appear that a new source is needed. However, you may find that less costly alternatives to a new source are actually a more appropriate solution. Before leaping into the complex process of developing a new source, make sure that more water is really needed. More effective use of existing water will often be a simpler and cheaper solution to the perceived need for "more".

In evaluating the quantity requirements of your system, some important issues to consider include:

- Are there other operational considerations that could help? For instance, is there a leak detection and repair program in place? Fixing one major leak can have a significant impact on the need for additional sources. Additional storage may also resolve shortages during peak use periods.
- Are conservation measures being practiced? If not, consider this option. AWWA has resource materials available (see **Appendix A**) to help in this assessment. Consider conservation alternatives available (including source and customer metering).

In many counties in the Northwest, there are entities (such as public utility districts) that operate and maintain smaller systems from a central location. This concept is often referred to as satellite system management. It enables small systems to benefit from the economies of scale that they cannot realize individually. For example, one certified operator may operate several small systems in a situation where none of the small systems independently could afford an operator. These economies can extend to equipment purchases, training, and joint projects such as storage, source development, or planning. Working with other purveyors can enhance the ability of small systems to develop services and is very much encouraged.

Determining Current Capacity

After determining system demand in gallons per minute (gpm) and gallons per day (gpd), inventory existing facilities and summarize their capacities. In order to do this, the system operator or manager needs to identify existing supply sources, their actual capacity to produce water, and the potential maximum capacity.

Every water system should record data for the following:

- Gallons per minute (gpm) and gallons per kilowatt-hour (gpkwh) for each pump
- Amount of water pumped or withdrawn from the source(s)
- Metered usage
- Unaccounted for water
- Peak day and peak month consumption
- Number of connections served

This data is necessary to successfully complete the four steps described in this chapter. Using this data you can estimate the amount of water produced by the system. To compute your water production information, you should review at least one year of data. Reviewing several years is preferable. It may be necessary to install meters or other flow measuring devices on your source(s) if they do not exist.

Consider several factors when evaluating the capacity of your supply. If your source(s) is/are well(s), keep in mind that pumps wear out. After many years of use, a pump may have a capacity of only 80 or 90 percent of its original capacity. If you obtain your water from a spring, its flow rate may change over time. Urbanization can reduce recharge and production from springs.

In addition to the physical factors described in the preceding paragraphs, regulatory considerations can also establish capacity. You should review the status of all currently held water rights, and consider the following questions:

- Are the water rights permitted or certified?
- What is their priority date?
- What are their total volumes? These limits may be instantaneous (your maximum gallons per minute), annual (the total acre-feet permitted) or seasonal (withdrawals limited to certain seasons).
- Are the water rights limited by "place of use"?
- Have you ever experienced any curtailments in the last ten years? If so, why?

Conversely, you may have a water right for more than your pumping capacity. Perhaps when the initial pumps were installed, the total water right was not needed. Now, with increased demand, it may be necessary to increase your pumping capacity if water is available in the aquifer or source.

Documenting Current Demands

Once all this information has been collected and evaluated, you can now document both the system's current production and its potential production capacity. The potential capacity may be either higher or lower than your current actual production.

One simple method to estimate average water used per day is to add up the water used in the system over a year and divide the total by 365 days. To get a number for peak day use you will need to review your water system's records to find the day with the highest use. If you do not keep daily water use records in your system, you can apply a "peaking factor" to your average water use. The average water used per day can be multiplied by a peaking factor to get an estimate of the peak water used in a day.

If you are going to use a peaking factor, you should gather information from nearby utilities, so that you are using a typical peaking factor for your area. Peaking factors in the Pacific Northwest typically range from 2.0 to 4.0, but may vary greatly depending on climate and the land-use(s) being served. State or local health program staff can provide typical water consumption figures. Phone numbers and addresses for health programs are listed in **Appendix A.**

Summarize water consumption data to determine current system needs and to serve as a basis for future demand projections. Be sure to evaluate the potential for water savings through conservation. Later sections discuss how to do this. In some instances, conservation can defer or even eliminate the need for additional sources.

Table 1 provides an example calculation of how to determine current water demands. Once you identify current supply needs, either from the perspective of addressing system growth or upgrading what are currently inadequate source capacities, you can project a total future additional demand. Once this is done, you can begin to identify potential sources capable of meeting that demand.

Table 1: Example of Current Water Demand Calculations

Number of services	500
Estimated Residential Population served	1500
Water Used in this example system in 1 year	54,750,000 gallons
Average Water Used per Day	150,000 gallons per day (gpd) (150,000 gpd = 54,750,000 gallons / 365 days)
Peak Water Used per Day	450,000 gpd (150,000 gpd average * peaking factor of 3.0)
Average Per Capita Water Use	100 gallons per capita per day (gpcd) (150,000 gpd / 1500 people)
Peak Per Capita Water Use	300 gpcd (450,000 gpd / 1500 people)

Projecting Future Demands

A trend analysis is the recommended forecasting methodology for systems with fewer than 1000 services. A trend analysis basically examines past water use on a per-capita basis, and applies it to population projections for a system's service area. It is important to note that many regulatory agencies are requiring conservation to be included in water demand forecasts. The trend analysis also needs to take into account adjustments for changes in land use.

To estimate future water demand a number of steps should be followed. These include:

- Defining your future service area;
- Projecting future growth;
- Estimating the effects of conservation; and
- Calculating future demand.

Define Service Area

The first step in projecting future demand is to delineate the existing and future service area of your system. If you have already delineated the service area, you need to make sure that it is consistent with your approved water system plan and with other governing local jurisdictions. For example, you cannot expand your service area over land where distribution pipes of another water system are already in the ground. Neither could you expand where another system has previously claimed a service area and registered it with the state.

If you do wish to expand your service area in the future, you must develop a water system plan to serve the expanded area and have the plan approved by the state. Expanding your service area may also carry additional responsibilities with it. For example, in the State of Washington, if your expanded service area includes areas currently served by a failing water system, you may be asked to take over the system and bring it into compliance with state and federal standards.

Check with your county agency, your state regional engineer, and nearby water systems for the locations of established service areas near yours. If a regional water plan has been prepared for your area, all established service areas should be included in it.

Project Future Growth

The next step to preparing your demand forecast is to develop a population projection for your system. Population projections that are consistent with county, regional, and state policies need to be developed. You should check with county or city planning officials to help develop your projections. Population projections are generally based on historic growth rates for an area, and usually include a high, low, and medium projection.

For example, if your system has grown from 500 to 525 connections in the past year, the growth rate would be five percent. If you projected growth at the same rate over the next year, your system would grow to (525 * 1.05 =) 551. This might be considered your medium projection. Your high and low projections might use growth rates of seven and three percent respectively. Historic data of many years (20 or more) are often used to develop growth rates.

Your growth projections also need to take into account any planned land-use changes in your area. To evaluate land use and zoning impacts in your area, review adopted land-use and zoning plans (available from county or city planning agencies), and estimate the saturation in your area. Saturation is the maximum potential population at the comprehensive plan's designated future zoning. **Table 2** provides an illustration of a high, medium and low growth projection for a water system that had 500 connections in 1991.

Consider Conservation

Consider the effects of conservation on your water demand forecast. It is recommended that all utilities have at least a basic water conservation plan. A written plan may be needed to obtain new water rights. If your system does not have individual meters, installing and reading meters can provide significant water savings. You may also want to evaluate your water rate schedule. If you charge a single monthly fee regardless of consumption, revising your rates to charge more to those who use more could save considerable amounts of water. Nearby water utilities, county and state health departments can help develop good conservation goals for your system.

Table 2: Example Growth Projections

Planning Horizon:	20 years	Historical Growth Rate:	5% per year
Year	**Low Projection** (3% / year)	**Medium Projection** (5% / year)	**High Projection** (7% / year)
1991 base	500	500	500
1992	515	525	535
1993	530	551	572
1994	546	579	613
1995	563	608	655
1996	580	638	701
1997	597	670	750
1998	615	704	803
1999	633	739	859
2000	652	776	919
2001	672	814	984
2002	692	855	1052
2003	713	898	1126
2004	734	943	1204
2005	756	990	1289
2006	779	1039	1380
2007	802	1091	1476
2008	826	1146	1579
2009	851	1203	1690
2010	877	1263	1808
2011	903	1327	1935

Once your water system has set goals for water conservation, these goals can be easily applied to the per capita water use estimate developed above. For example, if your system decides that it can reduce average and peak water use by 5% and 10% respectively, average and peak water demand projections would be developed that include conservation (**Table 3**). Gallons per capita can be converted to gallons per single-family connection by multiplying by a factor of 2.3 persons per household. If census data is available for your area, a more accurate factor may be available. If your service area contains multi-family and commercial development, you may want to convert them into equivalent single-family units (ERUs).

**Table 3:
Example Water Use Estimates with Conservation**

Daily Water Use	Water Use without Conservation		Water Use with Conservation	
	Per Capita	Per Connection	Per Capita	Per Connection
Average day (5% conservation)	100 gpd	230 gpd	95 gpd	219 gpd
Peak day (10% conservation)	300 gpd	690 gpd	270 gpd	621 gpd

Calculate Future Demand

Once the water use estimates are made taking into account conservation goals, the final step in making water demand projections can be taken. Simply multiply average and peak day water use estimates (with conservation from **Table 3**) by the number of people projected in your service area (**Table 2**). You will end up with high, medium, and low demand projections for each year that show both average day demand and peak day demand. **Table 4** shows the final calculations.

Table 4:

Example Water Demand Projections per Connection for a 20-Year Planning Horizon

Avg. Day = 219 gpd / conn
= 0.15 gpm / conn

Peak Day = 621 gpd / conn
= 0.43 gpm / conn

	Low Projection *(from Tables 2 & 3)*				Medium Projection *(from Tables 2 & 3)*				High Projection *(from Tables 2 & 3)*			
Year	Pop	Conn	Avg. Day (gpm)	Peak Day (gpm)	Pop	Conn	Avg. Day (gpm)	Peak Day (gpm)	Pop	Conn	Avg. Day (gpm)	Peak Day (gpm)
1991	500	217	33	94	500	217	33	94	500	217	33	93
1992	515	224	34	97	525	228	34	98	535	233	35	100
1993	530	231	35	99	551	240	36	103	572	249	38	107
1994	546	238	36	102	579	252	38	108	613	266	40	115
1995	563	245	37	106	608	264	40	114	655	285	43	123
1996	580	252	38	109	638	277	42	119	701	305	46	131
1997	597	260	39	112	670	291	44	125	750	326	49	140
1998	615	267	40	115	704	306	46	132	803	349	52	150
1999	633	275	41	119	739	321	48	138	859	374	56	161
2000	652	284	43	122	776	337	50	145	919	400	60	172
2001	672	292	44	126	814	354	53	152	984	428	64	184
2002	692	301	45	130	855	372	56	160	1052	458	69	197
2003	713	310	46	134	898	390	58	168	1126	490	73	211
2004	734	319	48	138	943	410	61	176	1204	524	79	225
2005	756	329	49	142	990	430	64	185	1289	561	84	241
2006	779	339	51	146	1039	452	68	194	1380	600	90	258
2007	802	349	52	150	1091	475	71	204	1476	642	96	276
2008	826	359	54	155	1146	498	75	214	1579	687	103	295
2009	851	370	56	160	1203	523	78	225	1690	735	110	316
2010	877	381	57	164	1263	549	82	236	1808	786	118	338
2011	903	393	59	169	1327	577	86	248	1935	841	126	362

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American Water Works Association
Pacific Northwest Section
Water Resource Committee

Chapter IV

WHERE WILL THE NEW SOURCE OF WATER COME FROM?

Potential Sources

Now that it has been determined that more water is needed and how much; the question remaining is where does that much water exist for you to develop. To address this question, consider the potential of approaching neighboring utilities to discuss cooperative projects or interties to provide the desired additional water.

The traditional new sources or equivalent new source capacity include:

- Direct surface diversion
- Additional reservoir storage
- Conjunctive or multiple use
- Developing new wells

New Source of Water

One alternative for locating a water source is to hire a hydrogeologist. The hydrogeologist can locate a water source by compiling site information, observing the existing site, mapping the site, and performing exploratory drilling. Under more complex conditions, geophysical methods may be used to determine geologic characteristics such as the depth to the water table, the number and depths of geologic layers, and the depth to bedrock.

There are several other ways to locate a water source. One way would be to compile the existing available data on water sources in the area. Existing wells can be a reliable source of information about the locations and depths of potential water sources. The state or other water systems may have well logs of other existing wells in the area. Contractors will sometimes know the depth to the ground water table.

After a source is located, there are other considerations such as the following:

- Site Ownership
- Hydrogeology
- Water quality
- Probability of future contamination
- Proximity to existing system

- Locations of existing utilities
- Local ordinances
- Construction considerations
  - Site access
  - Availability of disposal facilities

Availability

Identifying a potential source is not enough. The water must also be available from a water right point of view. This means reviewing the water rights situation with the appropriate state agency involved (see **Appendix A**) and securing your own right to use the water.

Water Quality

Availability is not the only concern. If the quality is not acceptable, additional expense will be incurred in treatment of the water. The results of all water quality tests should be permanently retained for future reference. The parameters to look at in determining water quality include:

- bacteriological,
- inorganic chemicals,
- organic chemicals,
- turbidity,
- color, and
- total organic carbon

These requirements are discussed in detail in the drinking water regulations for your state.

The well water assessment should be based on samples taken after pumping the well for an appropriate period of time. If the well is susceptible to salt water intrusion, the sample should be taken after the well stabilizes at the intended pumping rate, and the measured parameters should include total dissolved solids (TDS), conductivity, and turbidity.

If the water contains contaminants that would require treatment, it is necessary to measure parameters important to the treatment process but not required by the drinking water regulations. These parameters include dissolved organic carbon, alkalinity, calcium, magnesium, bicarbonate, etc.

Cost

You should generally follow the principles of cost-effectiveness and least-cost planning by identifying alternatives and pursuing them until they are no longer cost-effective (where the costs outweigh the benefits).

You should determine which mix of managing demand and supply source development options is the least-cost scenario for meeting future needs. The planning horizon can be as long as 50 years, although it should not be less than 20. The most cost-effective measures (most benefits per unit cost) should be accomplished first. Continue to look at different combinations of options until you are satisfied that you have identified the least-cost option. This is discussed in more detail in **Chapter V**.

Protection

The ability to protect the source from future contamination is a critical factor to consider before large investments are made in the development of a water source. When evaluating the feasibility of developing any new source, consideration should be given to the degree of water quality protection that will be needed to ensure the integrity and reliability of the source. Implementing source protection programs to reduce the risk of source contamination is generally far less costly than cleaning up contamination after it occurs. This guidebook primarily focuses on evaluating source protection needs for a new water supply, but the concepts could easily be generalized for use in implementing similar programs for existing sources as well. The following sections discuss some of the factors related to source protection such as vulnerability.

Identify Contamination Vulnerability and Source

Many factors can influence the level of control and degree of program complexity necessary to achieve adequate water quality protection for a potential water source. Your assessment of source protection needs may require on-site surveys and property research. A partial list of some important considerations is provided below:

- Physical attributes such as: topography, geology and soil characteristics (especially permeability, infiltration rate, and depth of source), vegetation, and drainage area above the potential intake or size of area contributing to the recharge of a wellsite.
- Ownership of watershed or aquifer recharge area and adjacent land
- Past land uses

- Current land uses
- Future land use/zoning
- Other potential sources of contamination:
  - Recreation (especially water contact sports, boating, fishing, and overnight uses such as camping)
  - Septic tanks
  - Forestry and activities related to silviculture (such as fertilizers, herbicides, harvest activities)
  - Animal populations (wild and domestic)
  - Chemical spills
  - Stormwater runoff
  - Wastewater plant discharges
  - Mining
  - Underground storage tanks
  - Industrial discharges
  - Agricultural runoff
  - Previous hazardous waste disposal sites
  - Highways
  - Pipelines
  - Railways
  - Salt water intrusion

Source Protection Measures

The measures necessary to achieve adequate control of activities within and adjacent to the watershed or identified recharge area depend upon the anticipated treatment requirements under current conditions, physical characteristics of the protection area, identified activities within the protection area, and associated contamination risks. For example, a potential well site that is located one mile down gradient of a large chemical manufacturing facility may face such a high risk that the site is eliminated from further consideration. In contrast, adequate water quality protection in a watershed where recreational activity is present may be provided through relatively simple measures such as:

- Public education activities
- Posting of signs that restrict use of vulnerable portions of the watershed
- Fencing certain critical areas adjacent to intakes

Measures that may be used to control the risk of contamination of potential water sources include:

- Restrictions on land use/zoning/development. "Special requirements" or prohibited uses in designated areas (buffer zones or other identified vulnerable areas)

- Plan review of potential development, with special water quality provisions for high risk projects
- Recreational use restrictions such as seasonal closures, areas of prohibited entry, controlled and supervised hunts, and/or limiting water contact activities and overnight use
- Installation and maintenance of pumpable sanitation facilities at all high use recreational sites
- Land acquisition or purchase of development rights
- Written agreements with land owners
- Careful selection of intake site or well location to minimize risk or eliminate impacts of potential contamination sources
- Watershed patrols and inspections with or without civil penalties for trespassing
- Public information and education
- Increased water quality monitoring, especially project or site specific monitoring within vulnerable areas

An important consideration during the evaluation of source protection requirements is the cost and complexity of providing protection. Even if it is determined that a source is viable and can be adequately protected, the cost to do so may be high. The estimated cost of source protection can be weighed against the cost to provide additional treatment or modify treatment techniques to reduce the required level of protection or the incremental cost of developing the next most desirable source. Personnel costs will likely be the largest component of a source protection program. Information about source protection program costs is included in the American Water Works Association Research Foundation (AWWARF) publication, ***"Effective Watershed Management".*** (See Appendix A for AWWA address and phone number).

An excellent source for cost information is through contacts with other utilities that have established programs. Several contacts are listed in ***"Effective Watershed Management"*** and others may be available from federal and state agencies. Engineering consultants can also provide cost estimating assistance.

New Wellhead Protection Requirements

Many states are in the process of developing specific requirements for protection of well sources. Although the specific requirements of wellhead programs vary from state to state, the following elements are common to each program:

- Delineation of zone of influence (the area of recharge for the well for a specified time of travel, usually 5 or 10 years)
- Inventory of contamination sources (sometimes referred to as a "windshield survey")
- Review of existing and future land use plans to identify potential future sources of contamination
- Establishment of protection measures (usually through ordinances and land use control) within the zone of influence to reduce risk from identified contamination sources and control risk from potential future contamination sources
- A plan, schedule, and budget for implementing identified protection measures
- Water quality monitoring
- Annual review of activities and report to state agency in charge of monitoring regulatory compliance

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Chapter V

HOW MUCH WILL IT COST?

Purpose

Cost is one parameter by which to compare resource options. The objective is to identify the least cost water resource options that provide the required water within the timeframe needed. This section discusses general cost estimating principles for long-range water supply planning.

Source evaluation must include: consideration of planning, engineering, construction, operations and maintenance, and other direct project costs. In addition, indirect, secondary, or external cost must be estimated and included in a full-cost evaluation. Some utilities give added consideration to conservation measures recognizing that they have less environmental impacts than new source development.

Least Cost Planning

One technique for resource evaluation that has been used by the electric industry for many years is now becoming very common for water resource evaluations and it is called "Integrated Resource Planning" or "Least Cost Planning". The technique compares the costs of supply side resources (new supply development or expansion and optimization of existing sources) with demand reduction programs (conservation, wastewater reuse, etc.) to select and prioritize water resource projects. Estimates of water savings and costs for demand side measures, and yields and costs for supply side measures must be made. In addition, the estimated savings from deferring capital expenditures on alternative supply side measures are attributed to conservation measures as "benefits" or reductions in cost. There are many sources of information for developing these costs and savings, which are provided later in this chapter under the heading of “Cost Estimating Resources”. This level of evaluation is complex and may require assistance from engineering consulting firms. This could soon be a requirement before a water right will be issued to a utility.

Cost Estimating Assumptions

Water resource evaluations are often conducted in stages. The initial evaluation may eliminate options based on very crude, relative cost comparisons along with other factors such as environmental considerations, public acceptance, timing, engineering feasibility, water quality, etc. For this initial evaluation, costs are often ballpark estimates that may vary from actual costs by as much as 50 percent in either direction. Cost may not be a primary consideration in the elimination of alternatives. Once the best resource options are identified, conceptual level cost estimates are generated to define those options that will be included in the utility's water supply plan for further study. These estimates are generally based on cost curve information, typical costs per unit yield or per horsepower of pumping capacity, past projects, and other conceptual level estimating techniques. Actual costs may vary from 30 percent more to 15 percent less than the conceptual level estimates. The object of the estimate is not to precisely determine the cost of each option; rather, it is to compare costs of one option relative to another. If consistent methodologies are used, this relative evaluation should be reasonably accurate.

Guidelines for preparing conceptual level estimates are provided below:

- The construction costs consists not only of capital costs, but also permit acquisition, engineering, and right-of-way costs.
  - Include costs for permit acquisition. In today's regulatory climate, environmental permitting may become a substantial component of project costs, and may even preclude further consideration of options with substantial impacts to environmentally sensitive areas.
  - Include engineering, contract document preparation, administrative and overhead costs, project management and inspection costs, and other related expenses. A professional engineer must stamp the water system plans. For municipal construction projects, engineering-related costs may range from 15 to 30 percent of the construction cost, depending on the size of the project.
  - Include costs for purchase of right-of-way, easement acquisition, and/or lease agreements. This cost is highly variable depending on the site location. If a large tract is needed, it may be necessary to determine the market value of the land through discussion with real estate agents or even by having the property appraised.
- Include a fair-sized contingency to cover site-specific construction constraints and details that have not been considered in the conceptual estimate. Typical contingencies for conceptual level estimates range from 15 to 30 percent of

construction costs. The contingency proportion may be reduced as the project develops and uncertainty is lessened.

- Include sales tax where appropriate. Sales tax should be taken as a percentage of the total taxable cost, including the construction contingency.
- To improve the accuracy of the comparison, a present worth of annualized cost comparisons should be made. Annualized cost is the equivalent cost per year of use and can be calculated using the following formula:

$$A = P\frac{i(1+i)^n}{(1+i)^n - 1}$$

Where:
A = Annualized cost over n years
P = Present value
i = Interest rate (annual)
n = Number of years (estimated life of project)

Annualized cost should include both capital and annual operations and maintenance costs (O&M). Annual O&M can be computed from historical information for similar facilities or can be based on general guidelines such as:

- Annual O&M expenses for a transmission facility are typically one-half percent of the transmission facility construction cost.
- For reservoirs, annual O&M expenses are typically one to two percent of the reservoir construction cost.
- For a new dam, annual O&M expenses are typically one-half to one percent of the construction cost of the dam. As the structure ages, the O&M percentage may be higher.
- For a pump station, annual O&M (labor and equipment) expenses are typically three to five percent of the construction cost of the pump station. Power is generally estimated separately, based on energy requirements at average annual flow, design total dynamic head, and local power costs. Typical values for hydraulic and motor efficiencies are 0.75 - 0.8.
- For a treatment facility, annual O&M (labor and equipment) expenses are typically three to five percent of the construction cost of the facility. You can estimate power and chemical costs based on past records of your utility. Another alternative is to estimate power requirements for pumping,

approximate dosage rates, chemical purchase costs, and consumption rate.

Cost Estimating Example

Appendix B may be used to get an idea of the costs associated with water well construction. The well design is a large factor in the total cost of obtaining a new water source.

An example of conceptual level cost estimating for constructing a new well is presented in this section. In the example, the following assumptions were made:

- Well depth is 200 feet. (Depth of the well will depend on the depth of the aquifer. Often the well will extend down to the bottom of the aquifer.)
- Assumed Peak Production Capacity is one million gallons per day (mgd) or about 700 gallons per minute (gpm). (The assumed peak production capacity is the projected peak day demand, as explained in **Chapter II**.)
- Assumed Well Casing Size is 12 inches. (Casing diameter should be slightly larger than the maximum horizontal pump dimension.)
- Pump Horsepower is 60 horsepower. (Pump horsepower depends on several factors such as the flow rate, the amount of head added by the pump, and the pump efficiency. **Appendix B** explains, in detail, how to determine the required pump horsepower.)

Table 5: Well Capital Cost

1.	Unit Cost For Well Construction	$ 30 per foot of depth per inch of casing diameter per pump
2.	Pump Costs	$ 400 per HP for submersible pump, including instrumentation and controls
3.	Well Pump Meter and Vault	$12,000 lump sum
4.	Miscellaneous Piping	$5000 (depends on distance from source to water system)
5.	Site Preparation	15 percent of construction
6.	Engineering Services	20 percent
7.	Contingency	25 percent

1. The unit cost for well construction is $30 per foot of depth per inch of casing per pump. With a well depth of 200 feet

and a casing diameter of 12 inches, well construction would cost $72,000.

2. **Table 5** gives an estimate of $400 per horsepower for submersible pumps, instrumentation, and controls. Actual pump costs can be obtained directly from the pump manufacturers. For a 60 horsepower pump, the pump would cost approximately $24,000.
3. Well pump meters are required to prove compliance with water rights and to apply for additional water rights. A supplier can provide cost information on the well pump meter and vault. For this example, the pump meter and vault cost $12,000.
4. The cost for miscellaneous piping depends on the distance from the pump to the system. The cost also depends on the hydraulics of the system, such as topography, available tie-in locations, number of valves required, etc. The piping for this example costs $5,000.
5. The cost of site preparation depends on the particular site. If the site will require extensive modifications in order to allow access for construction equipment, the percentage cost for site preparation will be higher than a site with fewer construction limitations. In this example with a total construction cost of $113,000, site preparation would cost an additional $16,950 (15% of $113,000).
6. Engineering services are approximately 20 percent, or $22,600, in this example.
7. Contingency is about 25 percent, or $38,138.

For this example, the total well capital cost is: ($72,000 + $24,000 + $12,000 + $5,000) * (1 + 0.15 + 0.2) * 1.25 for a total of $190,688.

Cost Estimating Resources

Many publications and other resources are useful, if available, to provide guidance with cost estimating. Some of these resources are listed below:

- US Army Corps of Engineering "Methodology for Areawide Planning Studies Documentation", EM 1110-2-502, Part 2 of 2, 28 November 1980.
- USEPA, "Microbiological Treatment Technologies and Costs for Surface Water Treatment Rule Compliance", no publication date.
- USEPA, "Standardized Costs for Water Distribution Systems", prepared by HDR Engineering, September, 1989.

- Engineering News Record, Construction Cost Index, and Graphs of costs for various types of construction projects.
- Historical information from your own utility on costs for various projects.
- Other utilities' experience.
- Engineering consulting firms.

For conservation costs and benefits evaluations, the following resources are available:

- Rocky Mountain Institute
- Conservation plans for various utilities including: Portland, OR; Seattle, WA; Redmond, WA; Tacoma, WA; Ashland, OR.
- Planning and Evaluating Conservation Measures. (Special Report No. 48) American Water Works Association, Chicago, Illinois, 1981.
- Maddaus, William O., Water Conservation, American Water Works Association, Denver, Colorado, 1987.

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Chapter VI

OBTAINING STATE AND LOCAL APPROVAL OF A NEW SUPPLY

Steps for the Approval of New Supplies for Public Water Systems

The state health department regulates public water systems, although additional local health and land use approvals are also commonly required. Water system plans are approved by county government and one or more state agencies.

The purpose of this chapter is to define the necessary steps in the process that a small water system must take to secure approvals for developing a new water supply. Suggestions to minimize complications are described.

A copy of the Rules and Regulations of the state regulations regarding public water systems should be obtained from the local health department or one of the state district offices (see **Appendix A)**. In order to clarify the procedures for seeking approval of small public water system sources, the steps in the process are outlined below.

Water Right

State law generally mandates that any person, municipal corporation, firm, irrigation district, association, corporation, or water user's association desiring to appropriate water for a beneficial use must make application for a permit to make such appropriation. A copy of the water right permit must be incorporated into the engineering report or plans and specifications when seeking approval.

An application for a water right does not guarantee that the permit will be granted. Therefore, the water right situation should be thoroughly investigated before the application is submitted. A typical water right may take two or three years, depending on the state. Because of the considerable time involved applying for a permit and the processing of a water permit application, it is prudent to make application as early as possible in order to facilitate the approval process.

Source Site Inspection

Prior to the development of a well as a public water supply source, site inspection and protection is usually required. Approval of a source site constitutes an evaluation of the site with respect to factors potentially affecting public health. It considers terrain, local or potential sources of contamination, the nature of the strata through which the water will flow, the evaluation of hydrological and geological data, and the depth of the aquifer. The development of springs and/or surface supplies as a water source requires special considerations.

Control Area

A control area is usually required based on the proximity and type of potential contamination to the source or if an analysis of the strata indicates that there may be an effect on the quality of the water. The local health agency or the state will assist you in determining the size of the control area, its configuration, and the nature of any restrictions.

Source Development

Water sources must be developed to assure the minimum possibility of contamination. Construction must be in compliance with the appropriate minimum standards. The well driller selected should be familiar with these standards.

Special considerations are required for spring or surface water development. Therefore, contact the local health department or the district engineer for minimum requirements for these sources.

Disinfection Facility

After a water source has been developed, the facility must be effectively disinfected before putting any portion of the system into service. The disinfection process must be performed according to the American Water Works Association (AWWA) or American Public Works Association (APWA) standard or another acceptable standard.

Water Quality

It cannot be emphasized too strongly that the responsibility for the ownership of a public water system does not end with approval by a governmental agency. Continued monitoring is critical in order to maintain local, state, and federal water quality requirements. Routine monitoring is required in the area of bacteriological sampling, organic and inorganic chemical analyses, turbidity and radionuclide analysis as well as many new, emerging regulations.

A bacteriological analysis of the raw water is required for all new systems being put into use, and routinely thereafter. System size generally dictates the number and frequency of bacteriological samples.

System Design

Prior to installing any portion of a new public water system source or any alterations of an existing public water system every water purveyor must develop plans and specifications for the proposed project with the aid of an engineer. You should engage an engineer who is familiar with the requirements of the regulations.

The requirements related to submission of plans and specifications for new water works are covered in the state regulations. Your engineer should become familiar with those requirements and adhere to them in preparing plans for your project. The following plans will usually be required for all small public water supplies:

1. Name of owner and address of owner.
2. Name and seal or stamp of design engineer.
3. Name of individual who will have operational responsibility.
4. Design: The system design must comply with the appropriate standards. Detailed plans and specifications for source development submitted for review normally include the following:
    a) Source location and design of well, including extent and placement of grouting, well log, well capacity, drawdown and static water level.
    b) Construction plans for well housing and other appropriate building construction.
    c) Manufacturer's name, capacity, and model type and number of all pumps, and type of chlorinators where disinfection is required.

Along with detailed plans and specifications, the following information should be provided:

1. Well site inspection made by the state or county health department representative.
2. Copies of easements, covenants, or ownership where necessary for well site protection.
3. Pump Test.
4. Well Log.
5. Water right permit number along with the amount of water allocation in the permit.
6. Plan for ownership and future operation of the system.
7. Evidence of compliance with applicable environmental laws.
8. Water Quality Analysis.
    a) Chemical: Chemical analysis of water from the

proposed water source must be provided and such analyses must show conformance to the standards as set forth in the state and federal regulations.

b) Bacteriological: A bacteriological analysis must be made of water from the source and must meet the state bacteriological standards.

Before a new water system can be constructed, plans and specifications must be submitted to the reviewing authority for approval.

Appendix A

American Society for Testing and Materials (ASTM) www.astm.org
100 Bar Harbor Drive
West Conshohocken, PA 19428
(610) 832-9500

American Water Works Association (AWWA) www.awwa.org
6666 West Quincy Avenue
Denver, CO 80235-3098
(303) 794-7711

Idaho State
Division of Environmental Quality
1410 N Hilton
Boise, ID 83706
(208) 373-0244

Idaho State www.accessidaho.org
Water Resources
1301 N Orchard
Boise, ID 83706-2237
(208) 327-7900

Idaho State
Western Region-Water Rights-Well Drilling-Stream Channel Protection
2735 Airport Way
Boise, ID 83705
(208) 334-2190

Oregon Department of Environmental Quality www.deq.state.or.us
811 SW 6th Avenue
Portland, OR 97204
Groundwater Protection (503) 229-6804
Surface Water Quality Protection (503) 229-6790

Oregon Health Division Drinking Water Section www.ohd.hr.state.or.us\dwp
P.O. Box 14450
Portland, OR 97293
(503) 731-4010

Oregon Water Resources Department www.wrd.state.or.us
158 12th St. NE
Salem, OR 97301-4172
(503) 378-3739

Water Rights	(503) 378-8455 x265
Well Development	(503) 378-8455 x265
Surface Water Development	(503) 378-8455 x265

Washington State Department of Ecology www.ecy.wa.gov/ecology/ecyhome.html
P.O. Box 47600
Olympia, WA 98504-7600
(360) 407-6000

Washington State Department of Health
P.O. Box 47822
Olympia, WA 98504-7822
(360) 236-4501

Washington State Department of Health
Eastern Regional Office
1500 W 4th Avenue, Suite 305
Spokane, WA 99204
(509) 456-5067

Washington State Department of Health
NW Regional Office
1511 3rd Avenue, Suite 719
Seattle, WA 98101
(206) 464-7670

Washington State Department of Health
SW Regional Office
P.O. Box 47823
Olympia, WA 98504-7823
(360) 664-0768

Appendix B

Costs of water wells are a function of the well design. The well design consists of the sizes and materials of the pump, casing, screen, gravel, grout, and construction methods.

Depth of Well

The depth of the well depends on the depth of the aquifer. As pumping occurs, the water adjacent to the well will decrease in depth. This decrease in depth from the original water elevation is called drawdown. Usually the well extends down to the bottom of the aquifer in order to maximize the allowable drawdown and yield, which is the amount of water that can be extracted from the aquifer without harmful consequences.

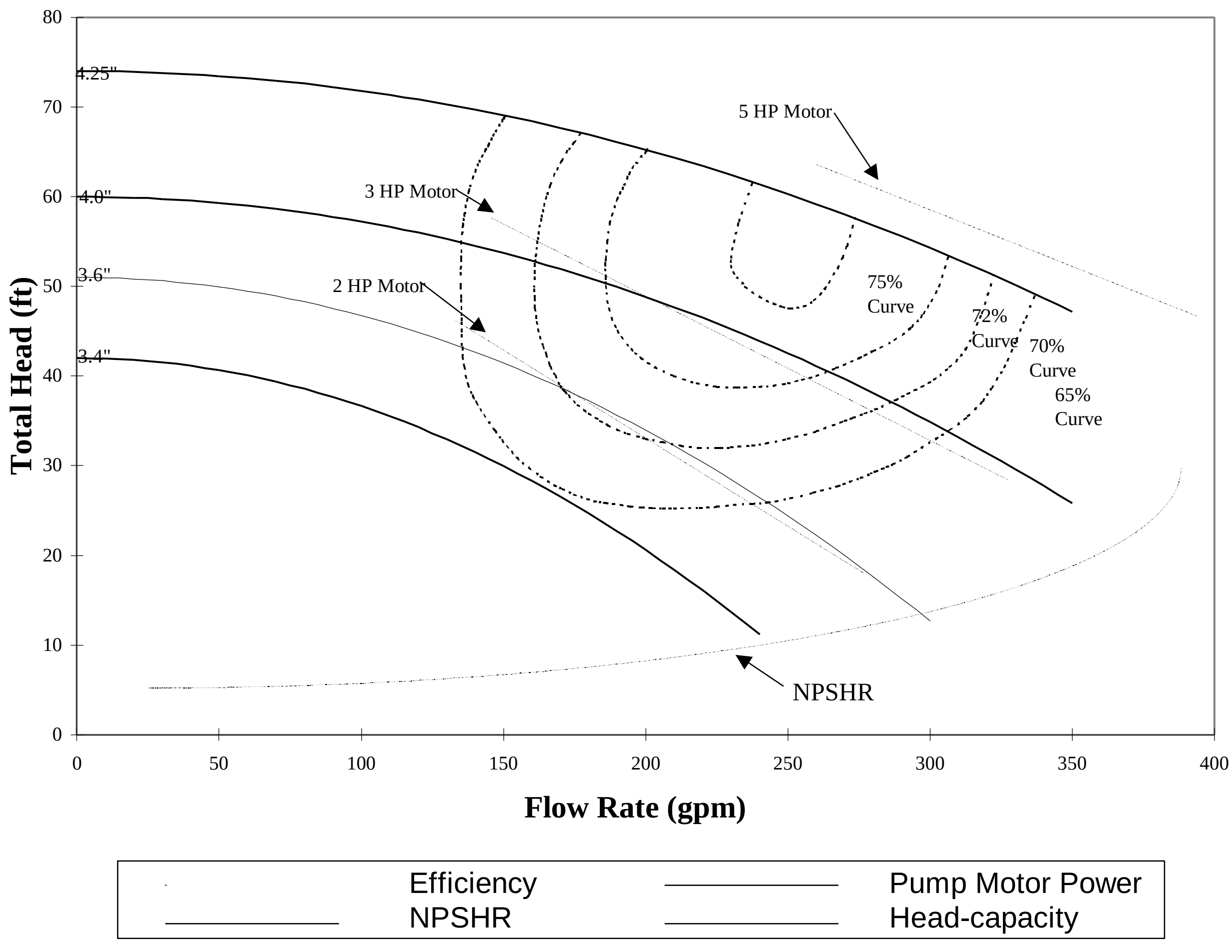
Pump

The capacity and the depth to the water table are used in the pump selection process. The required pumping rate can be determined from the projected future demand (**Chapter III**) and the pressure requirements.

The configuration and demands of the existing system should also be considered in the selection of a pump. The layout of the existing or proposed system as well as the depth to the water table will give an indication of how much head is required from the pump. Head is essentially energy in the forms of velocity, pressure, and elevation. When water flows through a pump, the water undergoes an increase in head. It should be kept in mind that as the water flows, its head will decrease due to friction and local losses (head losses in bends, constrictions, valves, etc.).

Pump performance curves, which can be obtained from pump manufacturers, will show various characteristics of a pump. These curves can be used to select the pump that will have the greatest efficiency at the given head and capacity. **Figure B1** gives an example of a pump performance curve.

Figure B1: Theoretical Pump Performance Curve



The head-capacity curve on pump performance curves show the relationship between the pressure head developed by a pump and the flow rate through the pump. The rotating component of a pump is called the impeller, and a different head-capacity curve is given for each impeller diameter. A pump with larger impeller diameter is able to develop higher heads and can operate at greater flow rates. For a given diameter, as the capacity increases, the head decreases.

The family of efficiency curves shows how efficiently a given pump is able to work under different conditions. **Figure B1** shows the efficiency varying from 65 percent to a peak efficiency of 75 percent.

The horsepower required for the pump is given on a separate set of curves. These curves show contours of equal horsepower. As the flow rate and head are increased, the required horsepower increases. The following formula can be used in calculating horsepower:

$$hp = \frac{Q * H}{3{,}960 * n}$$

Where:
hp = horsepower
Q = capacity (gpm)
H = TDH or total dynamic head (ft of water)
n = pump efficiency

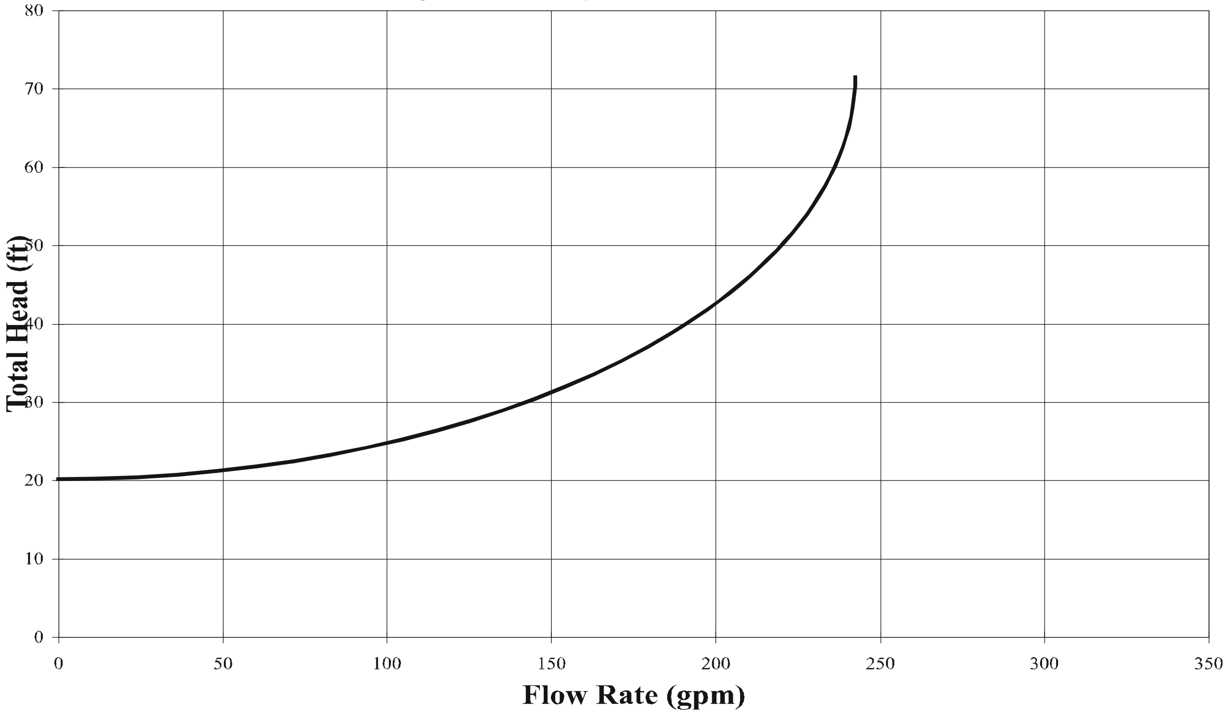
The pump performance curve labeled NPSHR in **Figure B1** shows the empirical relationship between the net positive suction head required for pump operation and the pump's capacity. The net positive suction head available (NPSHA) should always be greater than the NPSHR in order to avoid cavitation, which can cause significant damage to the pump. The NPSHA can be determined using the following formula:

$$NPSHA = H_a + H_s - H_f - H_{vp}$$

Where:
H_a = atmospheric pressure (ft of water)
H_s = elevation of water table above impeller while pumping
H_f = estimated friction loss in piping (ft of water)
H_{vp} = absolute vapor pressure of water at pumping temperature (ft of water)

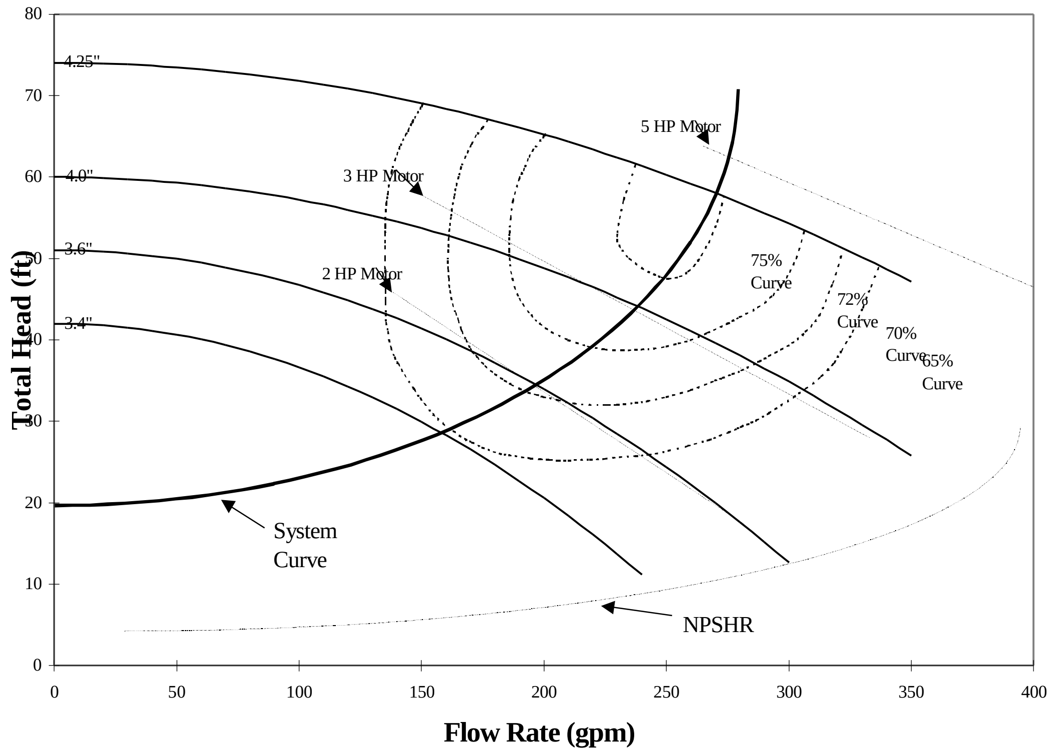
When selecting a water pump, a system curve must first be generated. The system curve is a plot of head loss versus flow rate. Sometimes two curves are plotted to show a range of flows. **Figure B2** is an example of a system curve. In this curve, the head at zero gpm is approximately 20 feet. This indicates that with no flow (i.e., no frictional losses), a static head of 20 feet is still required to lift the water to its destination.

Figure B2: System Curve



After a system curve has been constructed, it can be overlaid on the pump performance curves. **Figure B3** shows the combined system curve and performance curves. The intersection of the system curve and the head-capacity curve with the greatest efficiency will give the design point. The efficiency, horsepower, impeller diameter, head, and flow rate can then be read from the graph. For example, **Figure B3** would give a design point of 61.5 feet of head, 238 gallons per minute, 4.25-inch impeller diameter, 4.9 horsepower, and 75 percent efficiency. This design point gives the conditions at the greatest efficiency; the actual conditions will vary slightly from this point as fluctuations occur in the system. It may be prudent to look at a range of values before selecting a pump.

Figure B3: Theoretical Pump Performance and System Curves



	Efficiency		NPSHR Pump Motor Power
	System		Head-capacity

It is important to keep the well site conditions in mind when selecting a pump. For example, if the well water is highly corrosive or three-phase power is not available, the pump selection process might be altered. The pump manufacturer will have information to aid in the selection of a pump for the particular characteristics of the site.

Casing

The minimum required casing diameter can be determined by the maximum horizontal dimension of the pump.

AWWA Standards-January 1988 provides requirements for the casing design. Copies of *AWWA Standards-January 1988* may be obtained from AWWA's address, which is located in **Appendix A**. Table 2 in *AWWA Standards-January 1988* lists the required casing diameter for different pump sizes. Tables 3 and 4 in the standards list the minimum casing thicknesses for steel casings given the nominal diameter. Steel is the most common material used for water well casings, but if the chemical analysis at the site indicates highly corrosive conditions, another material, such as plastic, should be used. Casing material standards are given in the *Annual Book of ASTM Standards.* Copies of the *Annual Book of ASTM Standards* may be obtained from the American Society for Testing and Materials (ASTM) address located in **Appendix A**.

Screen

The selection of the drilling screen is based upon the pump's capacity at maximum efficiency. The screen should be completely submerged by water. The aperture (slot) entrance velocity of the water should be between 0.1 and 5 feet per second. (*AWWA Standards-January 1988*) AWWA gives guidelines for determining the aperture size of a screen and a formula for determining the length of the screen.

Gravel

A thin layer of gravel is used around well screens in order to obtain higher yields and to maximize the life of the screen. According to AWWA, the gravel layer must extend to at least 20 feet above the top of the well screen. The gravel should be disinfected and should consist mostly of rounded pieces.

Grout

Grout is used in water wells to minimize contamination to the well water, to stabilize the casing, and to protect the casing from corrosion. Grout consists of portland cement and water. Bentonite is often added to the grout mixture. *AWWA Standards-January 1988* discusses the proper procedures and materials for grouting and sealing the well.

Construction Methods

The drilling contractor decides the method of installation of the well casing depending on the stability of the underlying rock. The cable-tool method can be a very long process, and is often used only when there is very hard rock that would be difficult to penetrate using other methods. Rotary drilling is when a rotating drill bit is used to penetrate the ground. Mud, water, or air may be used as the drilling fluid to remove the stray soil from the drilled borehole. The drilling fluid should not permanently alter the physical properties or the quality of the well.

After construction of the water wells, a variety of tasks must be performed before the well may be put to use. The well must be developed, performance tested, disinfected, and tested for water quality. Well development removes native silts and clays or drilling mud from the borehole and the aquifer in order to maximize the capacity and efficiency of the well. During development, the aquifer and borehole wall are subjected to high levels of energy and the capacity and sand content are tested. Performance testing includes testing the well's water levels, pumping rates, and recovery times. Well disinfection involves quality testing; the temperature, pH, and dissolved gases should all be tested in the well water.

Cost Estimate

After a conceptual design of the water well is complete, it is possible to arrive at a cost estimate for the construction of the well. **Chapter V** contains some approximate unit cost estimates and a list of resources that may be useful in finding cost estimates.