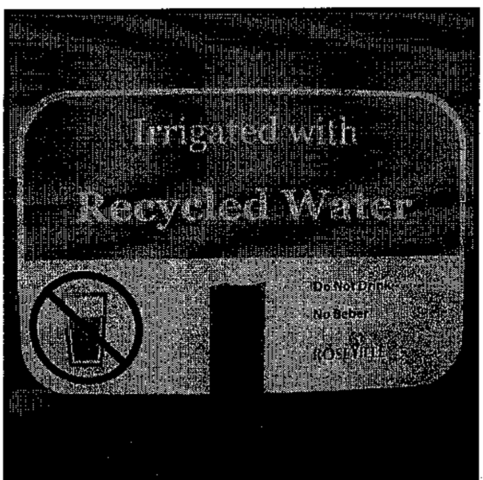

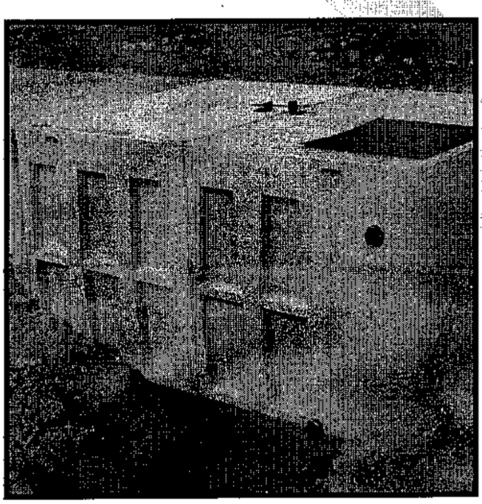

Alternative Water for Landscape Irrigation

2nd Edition

October 2013

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Irrigation
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About IA

The Irrigation Association is the leading membership organization for irrigation companies and professionals. Together with its members, IA is committed to promoting efficient irrigation technologies, products, and services and to long-term sustainability of water resources for future generations. IA serves its members and the industry by

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- ensuring industry standards and codes reflect irrigation best practices.
- providing forums that promote innovative solutions and efficient irrigation practices and products.

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Foreword

It is the vision of the Irrigation Association [IA] to be the recognized authority on irrigation. IA's mission is to promote efficient irrigation. Underlying this mission and vision is the hope that there will be adequate water for all needs on the planet, including water for irrigation. The demand for potable water increases exponentially with population growth, and many areas are experiencing a shortage. Additionally, there needs to be sufficient water remaining in the environment so that we may enjoy the ecological benefits that come from a healthy environment. Because human needs will always supplant irrigation, it is incumbent upon us to find and develop alternative sources. Almost all of the alternative sources are nonpotable — or unfit for direct human consumption. The usual alternative sources are rainwater, stormwater, treated effluent, condensate, and greywater. This manual delves into alternative sources and some of the issues that must be addressed in order to use these sources for irrigation while benefitting both people and the environment in a responsible way.

Acknowledgements

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Chapter 1

The Need for Alternative Irrigation Sources

Learning Objectives

The following objectives are the focus of chapter 1:

- discuss why alternatives to potable water are sought in the 21st century
- define nonpotable irrigation water
- understand the external factors that influence irrigation design

Introduction

Potable water systems have become commonplace over the last 50 years in urban infrastructure to the point where people may take them for granted. The quantity, quality, and convenience of consistent and local service have allowed cities and towns to grow rapidly in the twentieth century. However, as populations rise exponentially, the demand for clean water also grows. Not only do the basic everyday human needs for clean water such as drinking, cooking, and bathing tax a water distribution system, but commercial and industrial users require a safe water source for their employees, product manufacturing, and appearance. Unfortunately, many designated water sources and storage facilities designed in the twentieth century are approaching and will reach maximum output in the twenty-first century.

Almost all regional and municipal potable water purveyors recognize that supply availability is a task that requires planning now for the long term. These entities have produced bulletins, brochures, and information packages regarding the benefits of installing "low-flow" plumbing fixtures in homes and businesses. Some providers have even offered to install these fixtures as a courtesy to existing customers: the user receives free or discounted new plumbing and the provider maintains more of the water supply for new customers. Ultimately, water suppliers also recognize that there will be a tipping point where the current supply cannot meet demand. Given that finding new sources (when feasible) is costly, the first step to maintain a water resource is to limit current usage.

Availability for human consumption is always going to be first priority. After that, there is no guarantee if potable water will be available for irrigation. Water allocation is fraught with legal and political obstacles to hurdle. While the irrigation industry has made significant progress in the public awareness of irrigation water conservation through products, proper design, and education, there still remains some disconnect between purveyors and prospective users for irrigation. The result: water restrictions, bans, and limits that greatly reduce the potential of an irrigation system.

What if the only source of water was a potable service? After the proper installation of a backflow prevention device, the system is running without fault for a few years. Consider the following scenarios:

> *Scenario 1* — An unusually long drought occurs in the summer causing the water providers to restrict water consumption through water bans. These are the times when irrigation is needed most, but the purveyor has decided that more water must be conserved for uses that are deemed essential.
>
> *Scenario 2* — An allocation for irrigation water is granted at the inception of the project to meet the needs of plant material. This allocation is only valid for a few years and then the applicant is required to resubmit. The project was approved by public officials that no longer hold office. The new officials may not see the need for the water allocated, disagree with the original allocation, or have other ulterior political motives. The allocation is denied, cut drastically, or is imposed with more restrictions.
>
> *Scenario 3* — Difficult economic times call for water providers to find ways of generating revenue. Officials decide that consumers for irrigation should pay extra fees for nonessential uses. This makes the project cost-prohibitive, which jeopardizes economic sustainability.

All of these scenarios are plausible now and in the future. While quality potable water is currently convenient to acquire at low short-term costs, it is fair to assume that it will be harder to acquire in the future — especially at the desired rates or volumes. Once acquired, there are no guarantees that potable water taps for irrigation will remain in place for perpetuity. Needless to say, it is a difficult position to convey to a landscape owner that the irrigation system costing thousands of dollars to install may not have the future ability to protect the landscape that is worth tens or hundreds of thousands of dollars.

The ultimate goal of a landscape owner and irrigation system provider is autonomy over the water source. If the only option is municipal potable water, then this ideal is not possible. Someone or some governing body will have the outside authority to limit supply as they see fit, regardless of the self-imposed water saving measures. Total autonomy over water is difficult (and sometimes impossible) to achieve. However, if different water sources were made available, landscape projects may be considerably less restricted logistically and economically. The selection of one or a combination of different alternatives can remove some of the uncertainty of future water availability.

Definitions for Nonpotable Irrigation Water

Nonpotable water is a broadly based term with many different definitions. There are underlying principles that are consistent, but they are sometimes subjective leading to inconsistent definitions. This text will use the following prevalent definitions:

- ***nonpotable irrigation water*** — Any water that is considered not drinkable and poses no threat to humans and wildlife (health standpoint) or to plant material (landscape designer standpoint). The classification of nonpotable waters varies depending on the person, authority, or agency asked.
- ***nonpotable (alternatives) analysis*** — An assessment of all nonpotable options for water sources for irrigation. This assessment also includes using potable water and not irrigating at all. Sources are deemed viable or not viable from this analysis.

Summary

Going forward in the twentieth-first century, irrigation is not just about the science of watering crops and plant material efficiently. In past years, when water availability was deemed abundant, irrigation was primarily influenced by internal (technical) factors — tailoring the system to the owner's preference. With water availability for irrigation becoming more difficult to obtain, the external (nontechnical) factors will heavily influence the final outcome. As shown in figure 1-1, irrigation can be affected by economics, politics, and regulation. While irrigation professionals continue to educate the public on efficient watering practices, it is all for naught if a sustainable water source cannot be identified. Irrigation designers need to identify viable alternative irrigation water sources that can meet the demand of plant materials in the meteorological climate, as well as weathering the economic and political climates. A viable alternatives analysis should be the start of a sustainable irrigation design. Chapter 2 discusses the key factors in deciding to use an alternative water source.

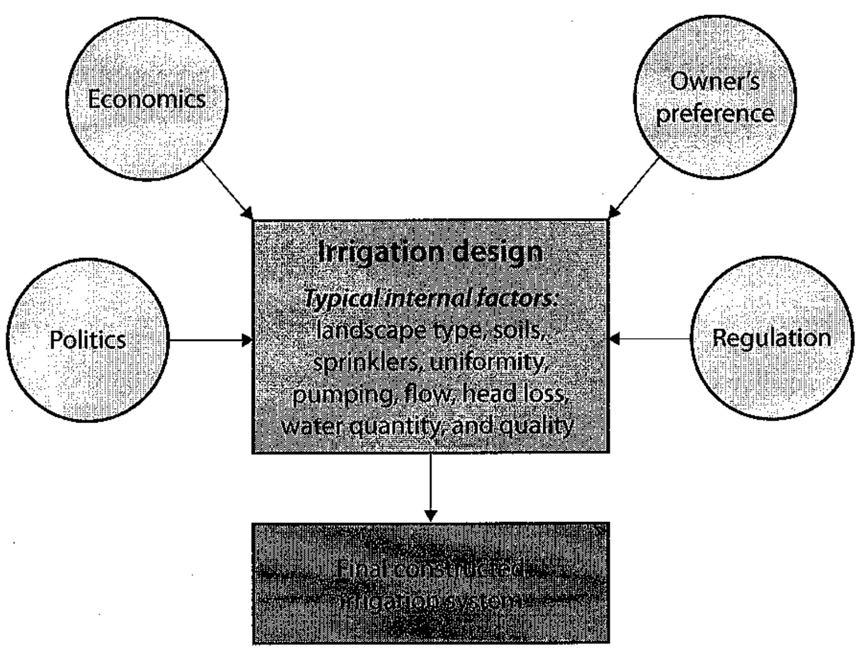


Figure 1-1
Internal and external factors of irrigation system design and construction

Practice Questions

1. Why should alternative water sources be considered?

2. What is the ultimate goal of using an alternative source?

3. What are the external factors affecting an irrigation system using alternative water sources?

Chapter 2

Alternative Water Properties to Consider

Learning Objectives

The following objectives are the focus of chapter 2:

- know the four key questions to ask for alternative water viability
- recognize the general pros and cons to each potable alternative
- conduct a thorough alternatives analysis on potential water sources

Four Questions

As discussed in the previous chapter, there are a number of alternative water sources, and each possible alternative contains a subset of viable water sources. While external factors may promote examining alternatives such as groundwater, rainwater harvesting, or treated gray water or effluent, in reality, the quantity available, quality for plants, regulation, and costs may identify only a few as viable alternatives to potable water. When identifying an alternative water source for irrigation, the following four questions should be asked:

1. Is the alternative source allowed? (***regulation***)
2. How much water is expected? (***water quantity***)
3. Is the water acceptable for use? (***water quality***)
4. What is the cost to acquire and use it? (***economics***)

The following is a cursory overview of these questions, which are discussed in chapters 3–6.

Regulation

Except in specific instances, total autonomy over irrigation is impossible to achieve. Whether using potable or nonpotable water, permission must usually be requested from a person or agency for continued use, set allocation, or to harvest water. Even if autonomy is possible, permission is often required to build the infrastructure to be self-sufficient with water. As previously discussed, potable water is managed by municipalities, government agencies, or large corporations. Any connection to a potable system is subject to the rules and regulations of these agencies. However, nonpotable water is often also subject to the authority of others.

There are numerous and innovative alternative ways of generating and harvesting water for irrigation. However, while these alternatives reduce or eliminate the need for potable water, they are not all allowed by law. With human-generated wastewater (black or gray water), government agencies often err on the side of caution with policy and regulation for potential reuse in populated areas. Exposure to microbial pathogens and chemicals is of utmost concern to regulators — especially with overhead irrigation. Agencies may heavily regulate, or disallow entirely, the use of any wastewater, making the alternative economically or legally not viable.

Groundwater can appear as a simple alternative because it often has nearly the same abundance and clarity as potable water by just installing a well. Some regulatory and certification authorities consider groundwater as a potable resource for this reason. However, groundwater levels drop during pumping, which impacts the land surrounding the well. Wetlands, rivers, and streams that have a hydrologic connection to the aquifer from which the well is drawing from may exhibit a drawdown in water levels. This would enable an environmental agency charged with the stewardship of these water resources to look unfavorably towards groundwater withdrawal. Moreover, some municipalities generate their supply through groundwater pumping. Regulation is set in place to protect their sustained yield by limiting withdrawal of other users. There also may be private groundwater rights, depending on the local precedent.

Direct surface water extraction is another seemingly easy way to generate water for irrigation. Aside from potential climate restrictions with rainfall frequency, there may be regulation similar to groundwater extraction that restricts the amount of water from these sources to maintain stream flow and water levels. Moreover, downstream water rights may be violated by extracting water upstream.

Regulation over rainwater harvesting varies greatly across the United States. Much of it is dependent on the local rights of downstream users of the generated runoff from storms and the perceived quality of water for reuse with irrigation. Harvesting techniques may be part of an overall stormwater management plan for a development site. Thus, any harvesting of runoff may be subject to local stormwater rules.

Water regulators desire to use the lowest quality water available for irrigation, yet they do not permit some nonpotable sources such as treated effluent or gray water. It is important to work with jurisdictional agencies in securing water sources (potable or otherwise) prior to beginning an irrigation project, as regulation is not mutually exclusive from the other water properties to consider.

Water Quantity

The unregulated quantity that a connection to a potable water system provides is unmatched. For years it has been perceived as an infinite source of water for all uses from drinking to irrigation. However, the reality is that potable supplies are limited by some capacity and are subject to limited allocation for nonhuman use to meet the needs for human consumption and safety (fire protection). When weighing options for irrigation water, it is extremely important to estimate the reliability and availability of water versus the peak demand of an irrigation system.

Groundwater wells vary widely in sustainable yield depending on the underlying geology of a site. Initial research and testing is crucial in determining the expected volume and flow from groundwater sources. Seasonal fluctuations in water levels may affect yield as well, but not nearly as much as with surface water extraction. A thorough investigation of geology, hydrology, and climate is required to ascertain fully expected yield.

Surface water extraction is subject to the local climate conditions. While long-term averages for stream flow and water levels are made on a yearly and even monthly basis, reliance on surface water is still subject to the chances of meteorological drought. As mentioned previously, quantity may also be limited greatly by regulation.

Rainwater harvesting is also subject to the same variances in seasonal climate as with surface waters. However, most surface waters maintain a minimum flow or water level — even during the driest times (referred to as a base flow). Storage provided for harvesting has the potential to run completely dry with many days or weeks of no rainfall. Generally, arid climates cannot utilize stormwater harvesting; however, even regions with temperate climates are subject to the risk of weeks without rainfall. These risks must be fully understood prior to construction of the irrigation system.

Treated effluent water is typically subject to the amount of people or industrial processes that can generate the wastewater. Relying on water that is generated by a few people is typically not a sound basis for water quantity expectation. To rely upon an area for enough water for irrigation, it must include a large population of people generating wastewater. With industries, there must be a clear understanding (a written agreement is recommended) of how much treated wastewater will be delivered. While industrial process waters are generally known in quantity over time, human-generated wastewater and irrigation demand may vary seasonally, such as with a resort or school.

Water Quality

By definition, potable water is water that is safe to be ingested by humans. Drinking water is not only potable but also palatable in that it generally is nonoffensive in taste, color, and odor to the people it services. It is a higher quality of water than required for plant sustainability. Typically, potable water is the most preferred alternative in terms of water quality, not only for plant material, but it also causes less degradation of equipment than most other sources.

Groundwater quality is very good in many circumstances, which is why some regulatory and certification criteria consider it potable. In many cases, very little treatment and finishing is required to make groundwater potable and palatable. Investigation into a site's history for contamination should always be the first step in water quality suitability. Subsurface contamination (soil or water) may be contained when undisturbed, but bringing tainted water to the surface from well pumping and ultimately irrigation brings new risks to human welfare. Historical site research should be conducted prior to well drilling. A thorough water quality test for minerals, inorganic compounds, and pH performed in a laboratory can identify potential problems for plants and equipment.

Natural surface waters tend to have a wide seasonal range for water quality. Moving waters (rivers and streams) generally have good water quality after spring runoff, provided no upstream contamination is present (e.g., from industry, etc.). Ponds and lakes vary in quality depending on use, season, and tributary waters. Typically, natural surface waters are considered resource areas by local and state authorities and may have water quality monitoring reports.

Stormwater can also have a wide range of water quality. From roofs, runoff quality can generally be very good with minimal dissolved or suspended contaminants. On the other hand, drainage from nonroof surfaces (parking lots, athletic fields, etc.) can be very poor, transporting a high volume of suspended solids and dissolved nutrients and solutes. In using either surface waters or stormwaters, an important concept to understand is that, in general, it is exposed to humans or human-made devices prior to entering a storage device (retention pond, tank, cistern, etc.). Consideration of these sources must include the impact of waterborne pathogens and microbial organisms. Without the benefit of protection of soil (groundwater) or a chemical and/or mechanical finishing process (treated effluent), a whole host of potential contaminants is possible with these irrigation sources. This consideration may require more downstream filtration and disinfection than other sources, depending on the type of irrigation to be installed.

Wastewater that comes from minor-impact human consumption (washing, bathing, and other nonsewage use) is gray water. Sewage-related water is designated black water. If allowed, gray water and black water can be treated and reused for nonhuman consumptive uses like toilet flushing and, of course, irrigation. Treated effluent receives its designation because it is the finished (treated) discharge flow (effluent) of refining processes. However, treated wastewater does not mean there are no water quality issues. Some effluent still contains a substantial amount of dissolved salts after treatment — a major problem for plant material (toxicity) and soil structure (clogging pore space). Other nutrients and elements can greatly disrupt the nutritional balance of plant material. Dilution and flushing with freshwater can overcome some of these concerns. Reverse osmosis [RO] treatment can eliminate the problem of dissolved salts. However, RO processes can also strip water of essential micronutrients that plants require and it is expensive. Quality assurance is critical when receiving off-site treated effluent from industry. The procedures for receiving consistent water quality should be explicitly discussed before entering into an agreement to receive wastewater effluent.

Economics

On a relative basis, potable water has been a preferred source of water because of the low initial capital cost to implement and the low cost of purchasing water. However, the rate increases in the price of potable water historically have outpaced the general inflation rate in many areas around the country. As this price gap expands over time, it will greatly impact the landscaping and maintenance budgets for many businesses and homeowners. Figure 2-1 presents a possible cash flow diagram highlighting these points. Moreover, as regulatory authorities prepare for populations and human consumption to increase, premiums to consume water for irrigation could be (and have been) levied on users. Therefore, a thorough nonpotable alternatives analysis needs to consider the economics of potential water sources. The savings from not using purchased water can be applied when determining the payback periods of installing infrastructure.

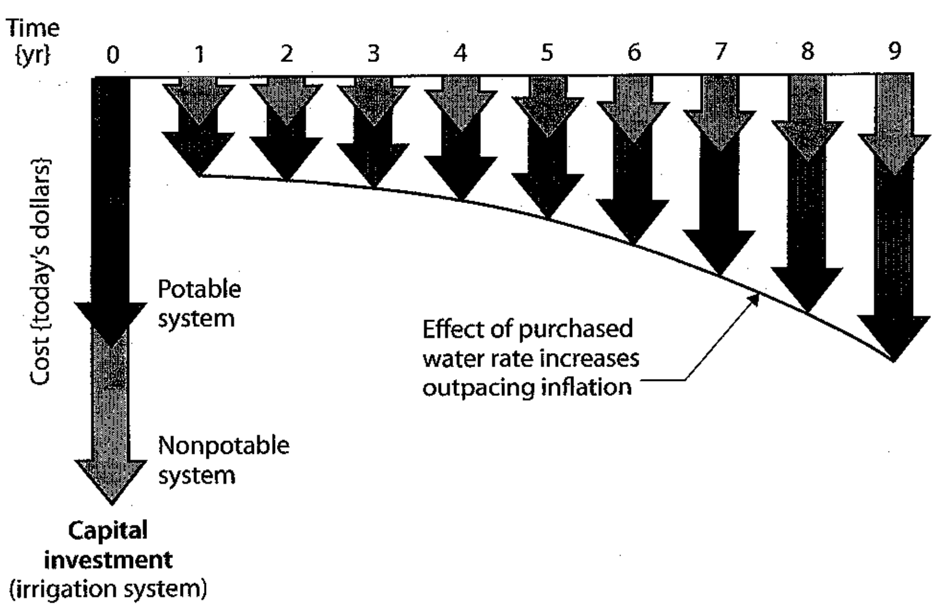


Figure 2-1
Cash flow diagram showing a general trend of future water consumption and maintenance costs (based on MWRA 30-year average rate increase at 6.7 percent vs. CPI of 2.9 percent)

The cost of installing groundwater infrastructure varies greatly depending on the system implemented and the prospect of finding water during exploration. Depending on water quality, the cost of routine maintenance of wells and pumping systems is relatively low. If the expected use of water for irrigation is less than the sustainable yield of the well and within regulatory limits, the cost of this water is relatively low (pumping electricity costs), making this alternative economically favorable in the long term.

Surface water infrastructure for irrigation generally has a higher initial cost than groundwater. The jurisdictional areas in and around rivers, lakes, and streams make it more difficult to use these surface water areas, thus driving up engineering and consulting fees. Construction within existing water bodies is considerably more difficult with mobilization and logistics. Regarding groundwater, if the irrigation consumption is less than the allowed withdrawal by regulation, the direct cost of this water is usually only the electricity to run the equipment.

When harvesting stormwater, additional storage must be provided by constructing a pond, installing tanks, etc. Routine maintenance is necessary to assure system performance. Economic analysis with risk and expected payback periods for the extra costs of providing storage is necessary to determine if harvesting is a viable alternative.

Treated effluent can be expensive if the treatment system is on-site, or it can be economically advantageous if receiving wastewater from off-site at little or no cost. The infrastructure required to produce clean, usable irrigation water from gray water is very costly. However, industries or other wastewater generators may seek entities to receive and use these waters as a means of disposal. In some cases, these industries may even pay the receiver of these waters (known as a tipping fee), as opposed to paying higher disposal fees. The economic arrangement between wastewater generator and receiver should be thoroughly discussed prior to any agreement.

Nonpotable Alternatives Analyses

Identifying potential irrigation sources should include a nonpotable alternatives analysis to determine which are viable. The four questions to ask when considering irrigation source alternatives are not mutually exclusive. For example, heavily regulated waters require more permitting, increasing consulting fees, and influencing project economics. Pumping or diverting more water may draw from regions of poor water quality. The intention of these questions is not to be discrete items on a checklist, but rather a holistic approach to identifying alternatives. It is quite common to combine different sources to meet the requirements for irrigation (see chap. 8). Table 2-1 shows a hypothetical alternatives analysis for one conceptual irrigation project; it is not typical of projects in general. This analysis should be conducted at the start of every irrigation project seeking to use resources other than potable sources.

In the broader sense, the term "alternative" implies that there is a choice between two or more options. It is quite possible that no viable alternatives exist, making it easy to decide which water source to use.

Table 2-1
Alternatives analysis for a hypothetical irrigation project

Hypothetical irrigation water source alternative analysis: John Doe Park, Anytown, USA					
Irrigation source	**Regulation**	**Quantity**	**Quality**	**Economics**	**Rank overall**
Potable	High	Dependable	Good	Poor (premium fees)	3 (viable)
Groundwater	Low	Low (requires storage)	Good	Moderate (storage cost)	1 (viable)
Surface water	High	High	Variable	Good	2 (viable)
Stormwater	Low	Variable	Poor	Poor	4 (not viable)
Treated effluent	High	Not readily available	Good	Poor (not readily available)	5 (not viable)
No irrigation	N/A	N/A	N/A	Very poor (lose plant material)	6 (not viable)
Decision: Use groundwater sources primarily with surface and potable sources as backup.					

Practice Questions

1. Which of the following is *NOT* a consideration when identifying an alternative water source if the landscape design cannot change?

   A. if the source is allowed
   B. if the water is acceptable for use
   C. the amount of water that is required
   D. the cost to acquire and use the water

2. Name four water quality parameters that should be tested.

   (1.) ______________________________

   (2.) ______________________________

   (3.) ______________________________

   (4.) ______________________________

3. Name four types of alternative water sources.

   (1.) ______________________________

   (2.) ______________________________

   (3.) ______________________________

   (4.) ______________________________

4. What are the pros and cons of using surface water as an alternative source?

   ____

   ____

   ____

   ____

   ____

Chapter 3

Groundwater

Learning Objectives

The following objectives are the focus of chapter 3:

- review the principles of well pumping for irrigation
- learn how to manage low-yielding irrigation wells
- highlight emerging methods of groundwater collection

An Alternative for Landscapes

Groundwater has been used for irrigation throughout most of human history — not just for agriculture in ancient history, but also for formal landscapes in recent centuries. For this reason, it may be hard to consider groundwater as an alternative water source. However, with the advent of potable water systems in recent decades, groundwater is often overlooked as an alternative for commercial and residential landscapes. Many irrigation professionals would suggest that the initial costs of drilling a well, installing a pump, and wiring a control system make irrigation projects economically unattainable. Given the projected costs of purchasing potable water, this viewpoint may be shortsighted.

Not all groundwater is pumped from deep wells. Other sources of groundwater such as underdrains, ditches, and infiltration basin recapture are different methods of accumulating irrigation water that may be viable alternatives. The following summarizes well-known and developing methods of using groundwater.

Wells: A Brief Overview

Wells can provide sufficient water volume, flow, and pressure (with a pump) to sustain an irrigation system if they are large enough and the geology is amenable. However, the yield of a well is highly variable and without guarantee — even with extensive knowledge of local geology. There is generally too much variability in the subsurface to be certain until performing well drilling and testing. It is prudent to consult with knowledgeable persons such as hydrogeologists and local well drillers who can provide an estimated possible (conservative) yield range prior to committing to the expense of exploratory drilling.

Well Types

Wells can be installed in two different geologic media: (1) sand and gravel, and (2) rock. The properties of a sand and gravel aquifer are readily obtained through soil sample borings or test pumping performed in the initial exploration phases of well construction. These properties include depth to groundwater, depth to bedrock, soil particle sizes (distribution), and water quality. From these initial tests, important design parameters such as well depth, screen size, and hydraulic conductivity are designed. A final well can be designed, installed, developed (to remove fines in and around the well screen), and tested. Note that the final testing of the installed well is the only way to determine the expected yield. While sand and gravel wells are more predictable than rock wells because of the properties of the aquifer that can be predetermined, there is no guarantee. Proper research and exploration should be the start of any well construction program.

Obviously, water cannot be transmitted through rock. Rock wells receive water through fractures and fissures within the bedrock that empty into the well hole. An impervious casing is installed to hold back the upper soil layers while the remaining well hole is open to its surrounding geology. Rock wells are drilled through the overlying soil layers and into the underlying bedrock — typically to a depth of hundreds of feet.

The bedrock material might consist of anything from granite found in the northern United States or limestone found in the southern part of the country. Granite, being much harder than limestone, is more difficult to drill through, resulting in increased time and cost. Fractures greatly range in size making initial estimates on yield very difficult. There are advanced methods of finding potential yield through fracture-trace analysis, aerial thermal imaging, and bedrock geology maps. Qualified well designers and hydrogeologists should be consulted before committing to drilling one or more wells to meet an irrigation demand.

Pumping

Pumps are used to withdraw well water either by suction lift or by submersion. The inlet for a suction lift pump is sealed to the top of the well casing at the ground surface. A vacuum is created that draws water from within the well to the pump and out to the irrigation system. A turbine pump can also be used if the well is relatively shallow (30 feet maximum) to set the pump. Typically, suction lift applications are used with shallow, driven (point) wells in sand and gravel. Driven wells are typically 2 inches in diameter or less.

Submersible pumps attached to discharge piping are lowered into the casing or borehole below the static water table. These pumps must be designed, not only for the operating pressures for the irrigation system, but also with the energy to move water up and out of the well. Sand and gravel aquifers exhibit drawdown (lowering of the water table) during well pumping. As shown in figure 3-1, theoretically, water moves in the aquifer radially towards the pump inlet. Drawdown occurs when the radius of pumping influence grows larger. Water not only moves horizontally but also vertically toward the pump screen creating a cone of depression. The bottom of this cone is the drawdown of the water table over the pump inlet.

If over-pumped beyond the safe yield of the well, the well is considered pumped dry. This can result in damage to the pump and motor. Long-term testing (8–72 hours) is performed on sand and gravel wells to assess their safe yield for irrigation well pump design.

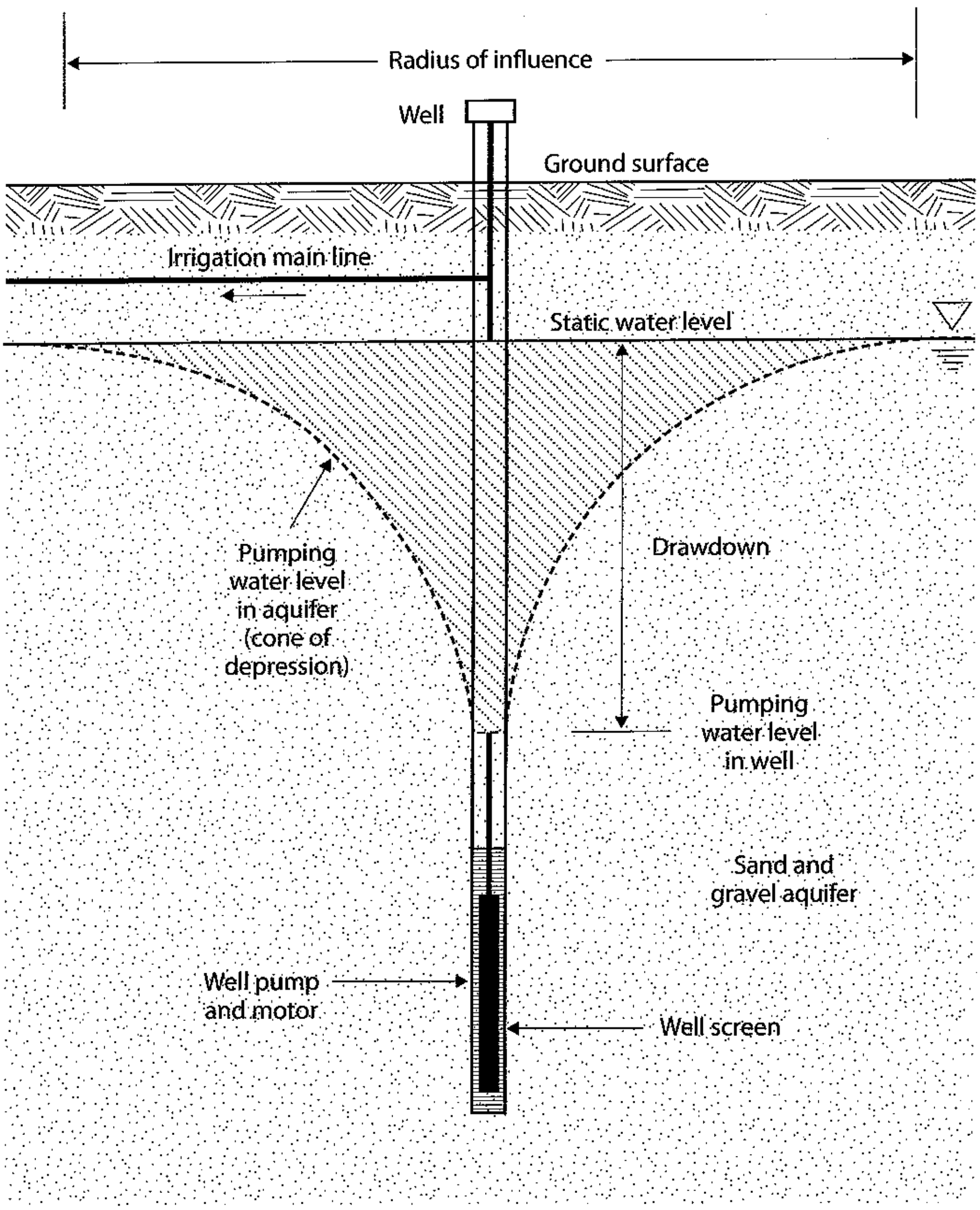


Figure 3-1
Typical effects on groundwater levels during well pumping

Rock wells act more like sumps compared to sand and gravel wells. Water flows into the bedrock borehole from fractures. They are considerably deeper than sand and gravel wells — typically hundreds of feet. A submersible pump is set near the bottom of the well to maximize effectiveness. Cleaning out fractures within the bedrock borehole enhances their ability to produce water. Hydrofracturing, or hydrofracking, is a method that uses pressurized water or small explosives to clean out debris and loose particles, thus widening and clearing the fractures at the borehole. Generally, there is some improvement after hydrofracturing, but the outcome is not certain. Smaller wells tend to show improvement more than larger ones. Once the final yield of a bedrock well is determined after testing, a pump is sized appropriately to maintain flow and deliver the pressure required for the irrigation system.

Regulation

The rights to groundwater in aquifers vary from state to state. Some states only allow for drilling and pumping influence within one's property (reasonable use rights) while others allow for directional drilling and pumping as needed (absolute ownership rights). Today, however, the regulation and standards of well construction and withdrawal amounts fall under the purview of state environmental agencies. This is because aquifers are viewed as critical environmental resources. Typically, there are strict maximum withdrawal and pumping influence restrictions that limit the overall size of wells and pumps. Consult local agencies or engineers on applicable rules and rights prior to committing to well water. For sustainable and green building certification, some organizations consider groundwater as potable. When seeking recognition for using alternative nonpotable water sources, it is very important to understand the organizational definition of potable water.

Water Quantity

As previously stated, water quantity is highly variable, depending on the location and geology. Unless a sound knowledge of the aquifer and precedent of existing wells exists, relying on higher yield wells is risky. It is possible to get high yielding wells (several hundred gallons per minute) within sand and gravel aquifers and in bedrock near major faults and veins. Nonetheless, withdrawal quantity is usually regulated.

If low yielding wells are developed, there are ways to overcome differences in requirement and availability. Tanks or ponds can be constructed to store pumped well water for later use in irrigation.

Example 3-1
Water flow requirements

An irrigation system for athletic fields requires a constant flow of 100 gpm over a 4-hour watering window from midnight – 4 a.m. every other day. A holding tank will be constructed to store well water. A separate irrigation pump will draw from this tank to the athletic fields. What is the minimum continuous flow from a well to the holding tank required to meet the demand of the irrigation system?

The total irrigation demand for each application to the athletic field is

$$\text{Irrigation volume \{gal\}} = \text{Flow \{gpm\}} \times \text{Watering window \{min\}}$$

$$= 100 \text{ gpm} \times 240 \text{ min}$$

$$= 24{,}000 \text{ gal}$$

From 4 a.m. today (end of last irrigation cycle) to 4 a.m. two days from now (end of next irrigation cycle), 24,000 gallons of water will need to have been stored. For a pump running continuously, 48 hours (2,880 minutes) will have elapsed.

$$\text{Min. well flow \{gpm\}} = \frac{\text{Irrigation volume \{gal\}}}{\text{Well run time \{min\}}}$$

$$= \frac{24{,}000 \text{ gal}}{2{,}880 \text{ min}}$$

$$= 8.33 \text{ gpm running continuously}$$

Therefore, even a low-yielding well can be used for higher flow applications when using a tank for storing groundwater. Note that because of the tank, all 24,000 gallons do not have to be available at the start of irrigation at midnight. Water can be pumped from the tank while it is being filled.

Water Quality

In uncontaminated aquifers, water quality is generally very good. In rural areas where municipal services are nonexistent, wells are constructed for domestic use, often with no treatment. Groundwater has neutral pH in most cases (6.5–8.0). Typical quality problems with wells include iron [Fe] and manganese [Mn]. Moderate amounts of iron and manganese can cause staining to buildings and hardscapes; in large amounts, they damage root zone soil structure. Near the ocean or other saline water bodies, the intrusion of salt water must be examined during pump tests. Table 3-1 describes the effects of iron concentration on irrigated landscapes. Treating iron can be accomplished chemically by sequestration (i.e., keeping iron in the solution to prevent rust particles from forming), or mechanically by aerification or agitation. The latter methods allow rust particles to form so they can be filtered out before reaching the irrigation system.

Table 3-1
Effects of iron concentration level on irrigation

Concentration (mg/L or ppm)	Possible effect
0.1	Drip irrigation clogged
0.2	Iron rust stains (walks, buildings)
0.3	EPA drinking water secondary contaminant limit for iron
2.0–5.0	Recommended maximums for irrigation
4.0–6.0	Plant tissue begins to exhibit toxicity

In general, irrigation water quality does not have to meet EPA drinking water standards; however, a test should be performed to ensure that plants are not introduced to toxins. A groundwater sample should be tested for constituents including, but not limited to, iron, boron, chloride, coliform bacteria, alkalinity, hardness, pH, and electrical conductivity.

It is vitally important to ensure that the underlying soils and aquifer are not contaminated. Bringing potentially toxic materials to the surface could cause a significant human health hazard — especially when dispensed through spray irrigation. Substantial research and possible testing should be completed prior to any well construction or pumping program.

Economics

Construction of a single well (sand and gravel or rock) with a pump can be cost-effective when considering the future costs of domestic water. Wells can become expensive during exploration and testing. Hiring knowledgeable professionals and properly managed drilling operations can keep costs to a minimum. Not all wells that are drilled will produce water; even when the geology is well known, there are too many variations in the aquifer and bedrock to assure a certain yield. Repeating the drilling process becomes expensive very quickly.

A long-term pumping test (8–48 hours) should be performed to estimate the sustainability of the well. It is possible for the drawdown characteristics of the well to change drastically throughout the year and with continuous use. Long-term testing can project the safe, continuous yield for future use. Testing a well for only a few hours can grossly overestimate its usefulness — possibly resulting in the need for more wells or reduced pumping capacity.

Other Viable Groundwater Sources

While the most common method for groundwater extraction is well pumping, irrigation water does not have to come strictly from deep wells. Groundwater close to the surface can be captured or collected for use if it meets water quality standards.

Foundation Underdrains

With some new building construction, a deep foundation and basement are built below the ground surface to support the structure. Depending on the location, these foundation walls are often constructed below the water table. Therefore, to keep the basement dry, underdrains are installed to convey near-surface groundwater away from the foundation walls. Typically, this water would be conveyed as quickly as possible toward storm sewers or infiltration basins. However, this "nuisance" water can be directed to a tank or pond for later irrigation consumption.

Unlike deep groundwater wells, near-surface groundwater is usually not considered potable. This source would be acceptable for sustainable irrigation design. Moreover, the local and state regulations for using this water are generally more lenient than with pumped wells.

Figure 3-2 shows a typical foundation underdrain system that can be used to collect water. Perforated gravity drainage pipes are installed at the base of the foundation wall to lower the immediate groundwater table (reducing the risk of basement flooding). The pipes flow to an underground tank or a pond. This system acts more like a low-yielding well described in example 3-1.

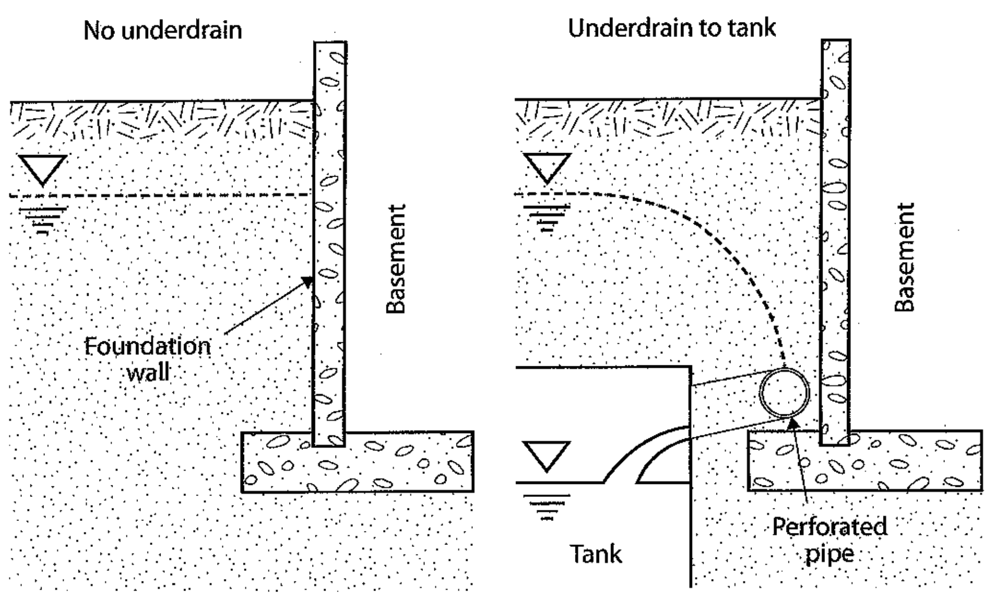


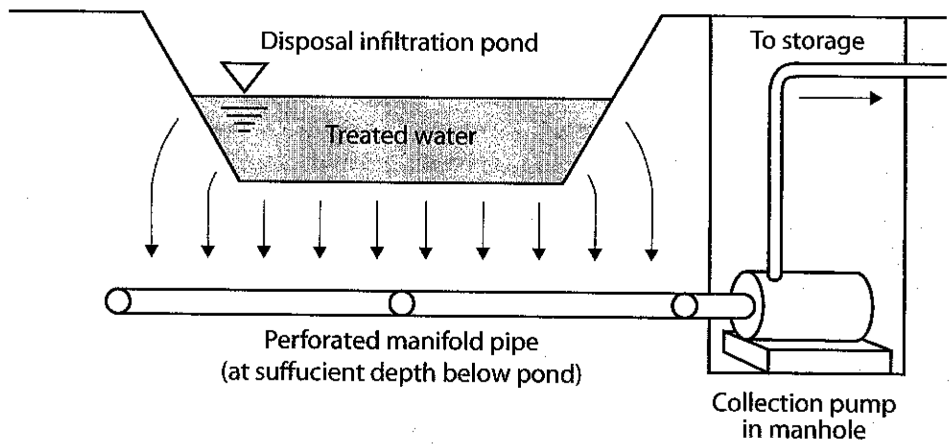
Figure 3-2
Foundation underdrainage stored for irrigation use

Reclaiming Infiltration Pond Water

Some parts of the United States allow treated wastewater or effluent that is disposed of through infiltration ponds to be reclaimed for irrigation. States view the reuse of treated wastewater differently regarding any human health risk to exposure. However, some states allow the reuse of this water after it has infiltrated through a sufficiently deep soil layer. Some regulatory agencies view water that has infiltrated a certain depth and received natural filtration to have returned to the groundwater system. Figure 3-3 demonstrates such a system. Consider also contacting the local water purveyor for additional requirements regarding use of treated wastewater.

Infiltration ponds are often used for disposing water; however, installing perforated manifold piping during pond construction opens the possibility of capturing water as it returns to the water table. As water infiltrates vertically through the soil, a pump can be used to draw this water into the piping manifold and out to a separate storage facility (tank or another pond) for irrigation. The available flow rate from this system generally is not enough to supply irrigation equipment directly; however, the volume could be substantial enough to warrant using as an alternative source.

Figure 3-3
Recaptured disposal infiltration pond water for irrigation



Summary

Groundwater has been a proven reliable source for irrigation water throughout human history. It is the preeminent alternative to domestic water in landscape irrigation. When designed and managed correctly, groundwater can be a cost-effective solution with its relative ease of construction and usually no future water purchases. However, regulation over aquifer pumping can be strict, as it is viewed as a potable water and environmental resource.

Pumping wells is not the only way to obtain groundwater for irrigation. Near-surface groundwater that would otherwise would be diverted away or return to the deep aquifer can be captured relatively efficiently using typical construction practices (e.g., foundation underdrains). The flow rates available from these methods are not usually sufficient to supply irrigation directly; however, the volume generated over the course of a day, week, etc., could be sufficient for a separate irrigation pump from which to draw.

Practice Questions

1. What types of pumps do wells require?

2. What is the critical design parameter in choosing a well?

3. An irrigation system for athletic fields requires a constant flow of 150 gpm over a 6-hour water window every third day. A well will be the water supply and will pump water into a storage tank. A separate pumping system will provide water from the tank to the irrigation system. What is the minimum well flow rate to provide enough water for the irrigation?

   A. 2.1 gpm
   B. 3.4 gpm
   C. 12.5 gpm
   D. 15.0 gpm

4. An irrigation system requires a constant flow of 90 gpm over a 5-hour water window every other day. A well will be the water supply and will pump water into a storage tank at a rate of 10 gpm. A separate pumping system will provide water from the tank to the irrigation system. What is the minimum storage tank size to provide enough water for the irrigation?

   A. 24,000 gallons
   B. 27,000 gallons
   C. 47,000 gallons
   D. 55,000 gallons

Practice Questions *cont.*

5. What is the maximum recommended iron content in parts per million for irrigation water?

   A. 1.0–3.0 ppm
   B. 2.0–5.0 ppm
   C. 3.0–6.0 ppm
   D. 4.0–6.0 ppm

6. What is the continuous flow required from a well that fills storage tanks for an irrigation system that requires 40 gpm over a 6-hour watering window watering every day?

SCRATCH PAD

7. What are potential groundwater sources other than groundwater wells?

Chapter 4

Surface Water

Learning Objectives

The following objectives are the focus of chapter 4:

- discuss the logistical design issues for flowing and nonflowing sources
- estimate the effective storage facilities
- understand how minimum flow maintenance affects allowed withdrawal

Surface Water Overview

Existing surface water is probably the most obvious and convenient source as an alternative source for landscape irrigation. Unlike groundwater where the yield is unknown until an exploration program is complete, the quantity of water from ponds, lakes, rivers, and streams is visible and can be readily found. This does not mean that the entire quantity residing in these water bodies is available for use. Water depth, quality, and regulation can reduce the potential availability for withdrawal. Many regulatory authorities view or even use surface water as a potable supply and not as an alternative source. However, if allowed, surface water is an excellent alternative to domestic potable water.

Surface water can be broken into two general categories: flowing (rivers and streams) and nonflowing (ponds and lakes). There are small currents within a pond or lake; however, this text makes the "bathtub" assumption that as water flows into a pond basin, the level is allowed to rise and eventually flow out. Nonflowing water bodies are examined first, followed by flowing bodies.

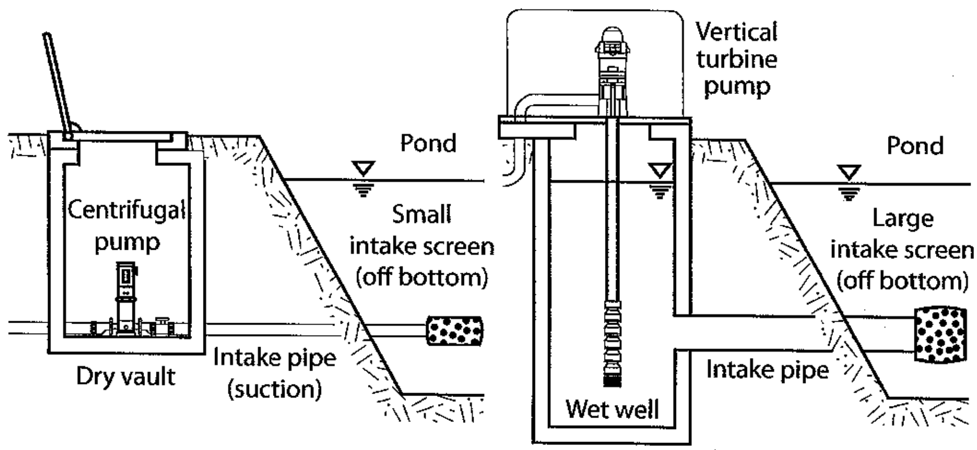
Nonflowing Surface Water

Ponds and lakes offer a great potential as alternative water sources for landscape irrigation. It is a logical choice to use the water surrounding and abutting landscapes for irrigating these features. Presuming that regulation allows for its use, there are some design considerations when using pond or lake water.

Natural and manmade ponds have an inlet (river, stream, or pipe) that allows water to flow into its basin. When the level rises above the basin outlet, water flows out and continues downstream. This text assumes that flow into a natural pond equals flow out of the pond. An example is a stream entering and leaving the pond. Manmade ponds may have varied flow entering the pond (by gravity or pumped discharge) and varied flow exiting the pond (from withdrawals for other use). Examples of manmade ponds are a stormwater retention basin or lagoon diverting stream flow.

Water is delivered to the landscape irrigation system from ponds and lakes by pumps fed through an intake pipe set below the normal water surface level. The intake pipe can feed a centrifugal pump directly (flooded suction) or discharge into a separate wet well from which a vertical turbine pump can draw. Figure 4-1 shows both arrangements. A centrifugal pump in suction lift application could also be implemented (see fig. 4-2), depending on aesthetics sensitivity.

Figure 4-1
Typical pumping arrangements for irrigation pumping from ponds



Each intake would be fashioned with an inlet screen to prevent debris or wildlife from entering the pump's suction end or wet well. The intake pipes for centrifugal pumps are small (pump inlet size) and their screens are finer. Submersible pumps generally are not used with ponds because they cannot generate the pressure and flow requirements for irrigation — although in special cases it may be possible.

The difference between ponds and lakes may seem somewhat obvious — a lake is generally perceived to be much larger than a pond. Some authorities have simply adopted size alone as the determining feature. However, others have included definitions such as, "a lake has depths where sunlight cannot reach" or "a pond can sustain rooted plant growth on its bottom." Nonetheless, depth of water is a critical factor in source quantity and quality. Lakes in this text are presumed to have sufficient depth and size to provide ample quantity and quality for landscape irrigation. Ponds are examined more closely.

After regulation, the depth of a pond will generally dictate whether it is a viable irrigation source. Pond depth affects three important factors in landscape irrigation (in order of importance):

1. Aesthetics
2. Water quality
3. Water quantity

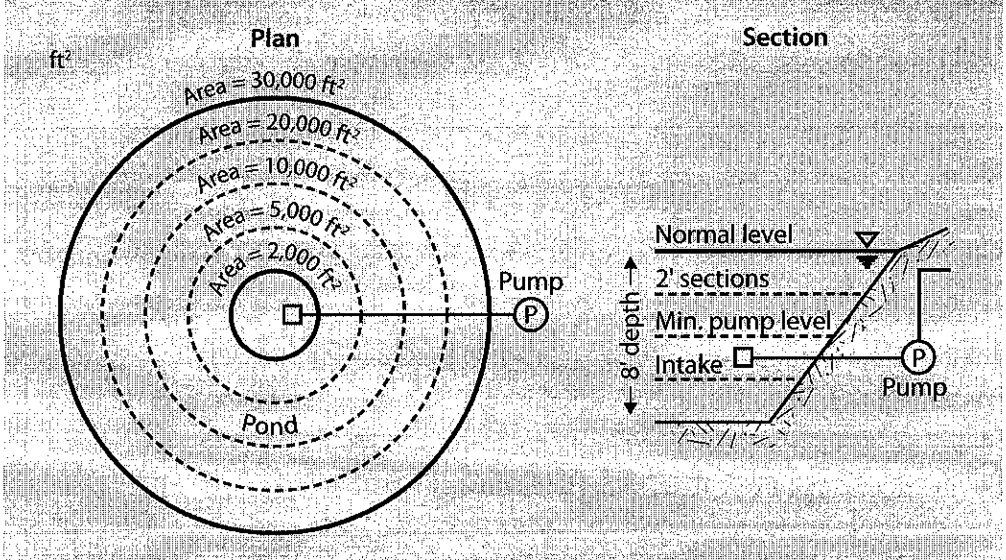
Generally, ponds surrounded by or alongside irrigated landscapes are the focal point of an architect's design. It would work against this design principle to have the pond dried out, overgrown, or silted in, creating an eyesore that was intended to be aesthetically pleasing. The irrigation designer must present expected water levels (based on quality and demand) and their subsequent effects to owners and architects for acceptability. The quality and quantity may be available to supply a sustainable irrigation source, but if the perceived aesthetic outcome is not acceptable, it may not matter.

Deep ponds generally have better water quality than shallow ponds. Sediment can accumulate further away from intake structures, water temperatures are cooler, and algae and plant growth is inhibited with deeper ponds. Ideally, a pond should be 5 feet deep so sunlight cannot penetrate to the bottom. Natural ponds have inlet and outlet streams and these currents circulate and aerate water. Deeper ponds also have stronger microcurrents, induced by temperature differences in the water, which also help circulation and prevent stagnation. For landscape irrigation with smaller sprinklers and drip systems, it is necessary to provide not only upstream filtration, but downstream as well — preferably to a 200-mesh (75-micron) level minimum.

When determining potential quantity, ponds should be examined for effective storage (actual water available) and not total storage (total water in the pond). Regulatory and design constraints such as pumping intake depth and aesthetics need to be considered prior to determining the availability of water. Example 4-2 is a typical design exercise in estimating water quantity.

Example 4-2
Pond sizing exercise

The pond in the figure below is the alternative water source for a park's landscape irrigation system. Given the pond's dimensions, what is (a) the total volume, (b) the effective storage if the pond can be drawn down to only 1 foot above the intake pipe (set 5 feet below normal level), and (c) the effective storage if the owner decides a 2-foot maximum drawdown shall be implemented to maintain the aesthetic appeal of the pond.



Example 4-2 *cont.*
Pond sizing exercise

Pond		Average					Section volume	
Depth (ft)	Area (ft²)		Area (ft²)		Depth (ft)		(ft³)	(gal)
8.0	2,000							
		>	3,500	×	2.0	=	7,000	52,360
6.0	5,000							
		>	7,500	×	2.0	=	15,000	112,200
4.0	10,000							
		>	15,000	×	2.0	=	30,000	224,400
2.0	20,000							
		>	25,000	×	2.0	=	50,000	374,000
0.0	30,000							
			TOTAL VOLUME				**102,000**	**762,960**

There are many ways to determine the volume of a pond. Simply multiplying the pond area by its depth is one rough method if limited information is provided. However, the figure above shows detailed dimensions and depths of the pond. This can be used to determine the volume of the pond available based on depth of water. The trapezoid method is used to calculate volume in the table above.

Because the areas at each section are known, take the average surface area for the top and bottom of each section and multiply by the depth. This yields the individual section volume (in cubic feet and converted to gallons by multiplying by 7.48). By adding all the sections together, the result is the total volume. Therefore, the answer to (a) is **762,960 gallons.**

The effective storage above the minimum pumping level over the intake pipe is the top 4 feet of the pond. Subtract the bottom two 2-foot sections to get the following:

$$762{,}960 - 52{,}360 - 112{,}200 = 598{,}400 \text{ gal}$$

The answer to (b) is **598,400 gallons.**

The owner's decision to limit the pond level to a 2-foot maximum for aesthetic purposes excludes the volume from the bottom three sections. Therefore, the answer to (c) is **374,000 gallons.**

If a pond's water level is a concern, it can be supplemented from another alternative source. Inflows from streams or rainwater can vary in amounts and frequency. Wells, other surface water bodies, and treated effluent could be used to transfer and supplement to manmade irrigation ponds (see example 3-1).

Natural pond water levels will vary seasonally; however, they generally will not run completely dry. The following are equally possible reasons why natural ponds stay full:

- constant inflows from rivers and streams
- ponds in lowland areas intercept groundwater table
- organic material and debris seal the pond

If water is constantly entering a pond, there will be water available in storage. Water levels will vary based on these seasonal flows. Even with low seasonal flows, some ponds still maintain sufficient water levels because they are connected to the groundwater table. Groundwater, like surface water, flows from higher to lower areas. Ponds are typically at the lower topographic areas of a region where groundwater and rivers terminate. Natural ponds and rivers that retain water even after long periods of no rainfall receive water from ground sources. This is further discussed in the "Regulation" section.

Ponds that are not connected completely to the groundwater table can maintain surface water levels if they are sealed. The bottoms of natural ponds have leaves, plants, sediment, and other organic material that accumulate and compact over time. This can form a seal that retains water from leaking and infiltrating to groundwater. Manmade irrigation ponds must be lined to prevent leakage from the bottom and sides and provide usable water for irrigation. A synthetic liner (rubber, PVC, or HDPE) can be installed as an impervious barrier to retain water. However, great care must be taken when installing synthetic liners, as rips and punctures will provide a way for water to escape. Other methods of sealing a manmade pond include the spreading of bentonite — a clay-based material usually refined in pellet or granular form. Bentonite's strong water absorbing properties act as a barrier to keep water from escaping. Natural clay can also be used as a liner when formed and compacted to a proper condition. A manmade pond is only as good as its ability to retain water.

Flowing Surface Water

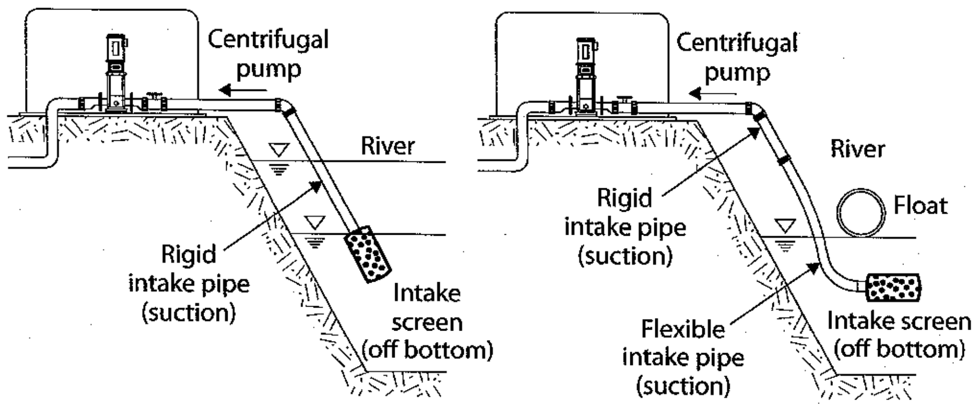
Rivers, streams, and ditches have issues similar to nonflowing surface water but also have unique obstacles to overcome. Water quality and quantity can be very good — better than ponds or lakes because of their constant circulation and movement. However, these water bodies are regulated heavily because they are considered by some agencies to be important potable and environmental resources. Another legal consideration is downstream rights; consumers of river waters expect a minimum amount of flow to be available. The law generally upholds this right to water for existing users.

Intake pipes for flowing water are similar to nonflowing sources — depth, screening, and filtration are all required. However, other considerations such as transported sediment, fish, and flooding mitigation must also be considered. Regulation does not generally permit the excavation of intake structures through existing riverbanks because of potential erosion. Therefore, a suction lift arrangement (see fig. 4-2) is selected to minimize disturbance. Another consideration with rivers is the force of flowing water against the intake structure. Pipes must be sized, specified, and supported appropriately to withstand bending forces from flow.

Water levels in rivers can fluctuate significantly. Rivers are active drainage paths subject to seasonal rainfall and groundwater patterns affecting the depth of flow. It is important to keep the intake constantly submerged so that water is always available. With flexible intake piping, floats can be attached so the intake stays below the water level (see fig. 4-2). In addition, the floats can keep the intake off the bottom of the riverbed and away from sediment and organic material.

Flooding is a great concern with river pumping stations. Flooding can result in costly damage to electrical and mechanical components. It is important to be cognizant of estimated flood zones and elevations (research FEMA maps). Structures and equipment should be set above the estimated floodplain elevations but still within the limits of the pump's net positive suction head required. Flooding also steers designers toward the pumping configurations in figure 4-2.

Figure 4-2
Centrifugal suction lift pumping applications with rivers (rigid and flexible intakes)



Regulation

The approval to use natural surface waters for irrigation is generally difficult — more difficult than groundwater approval. As stated earlier, regulatory agencies view surface water as important environmental resources to protect. Some surface waters may be considered or used as potable water supplies. Natural ponds will have considerably more permitting requirements on local, state, and federal levels than manmade ponds. Disturbance permits for construction in and around the water, withdrawal permits to use the water and permits for construction in navigable waterways are all applicable when seeking use of existing surface water. Research and consultation is necessary during the planning stages of weighing alternatives to domestic water.

Erosion and sediment control are major concerns for regulatory authorities. Disturbance to established pond shores and riverbanks from construction equipment creates loose soil with the potential to be carried away by water and deposited in lake bottoms and riverbanks. Erosion degrades the land at the site as well as water bodies downstream by sedimentation, thus changing the ecological balance. Designers need to demonstrate to regulatory authorities that the proper erosion control measures (silt fences, hay bales, tracking pads, etc.) are in place prior to construction. Ponds that are dewatered to install intake piping must filter discharge water typically through a temporary sediment basin. Dewatering discharge must be allowed to spread over land to reduce velocity that would otherwise scour shores and banks.

Agencies limit withdrawal from surface water bodies. Even if a seemingly infinite supply exists with a large lake or river, environmental agencies are concerned with ecological balance, and other commissions are concerned with use (consumption, recreation, and appearance). Lakes and rivers can be restricted for withdrawal based on drought and watering bans. Most agencies restrict withdrawal from rivers so that the minimum flow during the driest times of the year remains. Rivers flowing after long periods of no rainfall are receiving groundwater through the banks and bottom of the riverbed. The water during this time is known as baseflow, i.e., the minimum flow through the river. Statistical methods are used to determine baseflow. Generally, agencies will only allow a portion of the river's baseflow to be withdrawn (from 5 to 50 percent). Theoretically, this is to ensure that there will always be water within the river and stream, even during the driest periods for the local environment. Further restrictions on minimum flow may be imposed so that users downstream have sufficient water to supply their own needs.

If the surface water body meets the definition of a navigable waterway, any intake structure constructed would require a U.S. Army Corps of Engineers federal permit. Their jurisdiction (Rivers and Harbors Act of 1899) is to ensure safe commerce and travel over waters of the United States. The Army Corps also requires a permit for any fill or dredged materials that enter the waterway (under the Clean Water Act of 1987). Fill could be pipe supports, original material excavated, and then replaced, or foreign material entering the pond. These permits, while straightforward in application, have a long review period prior to approval. If a federal permit is necessary, allow plenty of time in the planning process to obtain one.

Water Quantity

The quantity of water needed varies with the time of year and the project. Large landscape projects (parks, ball fields, etc.) require substantial surface water supplies found in ponds and lakes. Smaller landscape projects may be able to use small ponds or rivers. However, if flowing surface water is used, be aware of the fluctuations and availability of water due to seasonal climate and regulation. If the project is appropriately sized, surface water can provide ample resources to a landscape irrigation system.

Water Quality

Water quality can be very good depending on the existing conditions. Lakes and ponds with active streams have excellent circulation. Surface water quality is best when the intake is deep enough to draw cool water, but not too deep to draw in sediment and debris from the bottom. An intake screen should be installed to prevent large objects (leaves, sticks, and fish) from entering the pump suction side. Surface water transports suspended solids and organic material that could easily enter the irrigation system through the intake. Installing filtration downstream of the pump discharge to protect irrigation equipment is highly recommended. Sand and media filters should be sized appropriately for system capacity and requirements. Also, seasonal issues such as additional debris in the spring and ice damage to intakes over the winter should be considered.

Economics

The only construction needed to draw water from a natural pond relates to the pumping station. Constructing a pond is expensive and possible only if there is adequate space. Typically for landscape irrigation projects, if a pond is constructed it is already part of a stormwater management design by an engineer (see chap. 5). Rivers with ample supply typically can be used by simply dropping a suction line into the flowing water body with either a rigid or flexible intake pipe. Pump stations vary in cost; simple systems can be reasonably priced while more control-intensive and logic-based systems will increase the price dramatically. The water itself is typically free — making surface water an attractive alternative.

Costs for surface water must include the time and effort needed to deal with permitting agencies and committees. It is critical to have preapplication meetings with the permit decision-makers so they understand the project and so that the designer understands their requirements. It may be that surface water withdrawal is not allowed at all; therefore, it would be better to find out the legality of the water source prior to investing heavily in the project. Applying for permits requires providing information and completing an ample amount of paperwork. Seek consultation from those who are familiar with the application process, including the permitting agencies themselves. Agencies know they ask for large amounts of information; typically, they are very willing to describe explicitly what is needed so multiple submissions are not required.

Summary

Rivers or ponds near landscape projects are ideal as alternative supply sources if the conditions are right. Although it is standard irrigation practice, the use of surface water is heavily regulated because of the environmental and water resource benefits provided to people and wildlife species.

Practice Questions

1. Name four types of surface water supplies.

   (1.) ______________________________

   (2.) ______________________________

   (3.) ______________________________

   (4.) ______________________________

2. Which of the following is NOT a factor affected by pond depth?

   A. water quality
   B. water quantity
   C. visual aesthetics
   D. availability of use

3. If a pond has a surface area of 1 acre and a depth of 8 feet, how much water is available for irrigation? Assume the pond walls are vertical and the pump inlet is 2 feet above the pond bottom.

   A. 163,000 gallons
   B. 217,000 gallons
   C. 1.9 million gallons
   D. 2.6 million gallons

4. What is the baseflow of a river or stream?

   A. water contributed to the river from groundwater sources
   B. amount of water that flows through the lower 10 percent of the river
   C. minimum amount of water than can be withdrawn from a river

5. How much water is available in the upper foot of a 2-acre pond, assuming straight sides?

   ____

   ____

   ____

Practice Questions *cont.*

6. Name two problems with using streams or rivers as an alternative source.

   (1.) ______________________________

   (2.) ______________________________

7. What possible regulations will impact the use of surface water as an irrigation source?

   ____

   ____

   ____

   ____

Chapter 5

Rainwater Harvesting

Learning Objectives

The following objectives are the focus of chapter 5:

- understand the key components in estimating runoff potential
- learn how rainwater harvesting is a "double savings" for irrigation
- set up an accounting method to estimate risk and size tanks

Introductory Concepts

Irrigation is an artificial means of supplementing natural rainfall for landscapes and agriculture. Therefore, irrigation is actually the secondary water source for plants, with rainfall being the primary source. This concept can be proven simply: if it rains sufficiently, no irrigation is necessary. If it does not rain sufficiently, then irrigation is necessary. Rainfall is an important part of the irrigation design program in temperate climates.

While seasonal totals for rainfall are well established, it is difficult to predict the frequency, location, and amount of individual storm events at any given point in time. Irrigation takes the uncertainty out of the potential for extended periods of no rain. However, when it rains, water can be harvested from surface runoff and stored for later use. This increases the contribution of the primary rainfall source and reduces the reliance on the secondary irrigation source. Therefore, rainwater harvesting could be an alternative to traditional potable irrigation sources.

Design Considerations

The effectiveness of rainwater harvesting is predicated on four design parameters:

- historical local climate
- area of catchment harvesting water
- irrigation demand
- storage provided

Historical Local Climate

Not all regions are conducive to rainwater harvesting. Typically, only sites located in temperate climates (i.e., those without extreme temperature or precipitation patterns) could consider harvested rainwater as a viable alternative water source. Arid climates do not have frequent enough rainstorms to consider harvesting. A temperate climate also has a smaller precipitation deficit in the summer than an arid climate. Precipitation deficit is the shortage between evapotranspiration and precipitation over a given timeframe (month, year, etc.). Therefore, the need for supplemental irrigation is less in temperate zones — but still required.

Obtaining historical rainfall records for an area will provide insight as to whether rainwater harvesting is worth considering.

Example 5-1
Feasibility of rainwater harvesting example

Consider a potential rainwater harvesting design to store roof runoff in a tank and irrigate a small planter bed. Historical precipitation data for this area shows that there are 8 rainfall events (days) in July of 0.2 inches or more which result in a net storage of 2.4 inches, all of which can be stored. Average daily ET is 0.20 inches. Is this a viable system?

Recall the previous explanation of rainfall as the primary water source. With rainwater harvesting, *if it rains sufficiently, no irrigation is necessary AND water is accumulated for later when rainfall is insufficient.* This is the biggest advantage to using a rainwater harvesting system for irrigation. Scheduling for irrigation in July is as follows:

$$31 \text{ total irrigation days (July)} - 8 \text{ days of sufficient rainfall (by rain sensor)} = 23 \text{ net irrigation days (July)}$$

$$\frac{2.4 \text{ in. of stored rain}}{0.2 \text{ in./day of irrigation}} = 12 \text{ days of stored rainwater}$$

$$23 \text{ net irrigation days (July)} - 12 \text{ days of stored rainwater} = 11 \text{ irrigation days from secondary source (July)}$$

The answer to the question in example 5-1 is not simply yes or no. Irrigation demand has been reduced by 65 percent, irrigating only 11 of 31 days in July on average. However, a secondary water source (presumably domestic water) is still necessary on those 11 days. Will the initial cost of a rainfall system be offset by potable water savings in a reasonable amount of time? If the goal is to have a completely nonpotable system, is the risk of not irrigating these 11 days (allowing for moisture depletion) acceptable? Example 5-1 is a simplified example of sizing a rainwater harvesting system.

The flaw in the analysis of example 5-1 is that is assumes *average* conditions will occur. Temperate climates are still subject to abnormally dry periods. In this case, what happens to plant material? A sound understanding of economics and risk is required before designing a harvesting system. The end user must be aware of the costs and risks as part of the design process. However, risk can be mitigated partially by modifying the other three design parameters.

Catchment Area

As it rains, at some point water begins to collect on a surface. When enough water has accumulated on the surface, it begins to flow downhill. This water is known as runoff. Runoff follows its natural drainage path by gravity and eventually terminates in streams, rivers, and the ocean. The amount of rainfall required to generate runoff is dependent on the surface type and intensity. Generally, the less pervious the surface is, the less rainfall is required. With pervious surfaces, some water enters the ground through infiltration while the excess forms runoff. Surfaces that permit no infiltration are known as impervious surfaces. Almost all of the rainfall (+/– 95 percent) that hits impervious surfaces is generated as runoff (except for a small amount that remains adsorbed to the surface).

A catchment area is determined by a point of reference on a topographic or drainage map. It is defined as the area from which runoff will eventually flow through the reference point. Runoff could flow over land or be collected and conveyed through drainage structures (pipes, catch basins, etc.). When dealing with larger rivers and streams, catchment areas are generally referred to as watersheds. However, for irrigation purposes, rainwater harvesting typically involves catchment areas much smaller than the watershed scale. Larger catchment areas generate more runoff and larger harvesting potential.

When identifying potential catchment areas for rainwater harvesting, it is important to include areas that will generate the most runoff (i.e., impervious areas). Typical impervious areas used for rainwater harvesting include roofs, parking lots, patios, etc. Runoff generation from pervious surfaces requires large rainstorms and intensities. Therefore, it is best to avoid using pervious surfaces for the harvested catchment area because of the infrequency of the storms required to generate runoff. If pervious surfaces are used for rainwater harvesting, seek engineering consultation during the design process. Using impervious surfaces mitigates some of the risk in generating runoff to be used for irrigation.

Example 5-2
Determining rainwater harvesting amount

How much rainwater can be harvested during a 1-inch storm falling over a roof with a catchment area of 4,000 square feet directed toward a tank?

When the amount of a storm is reported, it is the rainfall depth. To obtain the volume of runoff collected, the formula is simply area multiplied by the depth. However, some rainfall adheres to the roof's impervious surface and is not available as runoff. It is prudent to be conservative and factor in a runoff coefficient [C_R]. For impervious surfaces, a coefficient of 0.90–0.95 (i.e., 90–95 percent of rainfall turns to runoff) is acceptable. The coefficient varies depending on the type of surface. The expected runoff to be harvested is as follows:

Equation 5-1
Runoff volume

$$V_{runoff} = 0.623 \times C_R \times D_R \times A$$

where

V_{runoff} = total runoff generated {gal}
0.623 = unit conversion constant
C_R = runoff coefficient (a number of 0–1)
D_R = depth of rainfall {in.}
A = catchment area {ft²}

$$V_{runoff} = 0.623 \times 0.90 \times 1 \times 4{,}000$$
$$= 2{,}243 \text{ gal}$$

Irrigation Demand

After determining the catchment area for rainwater harvesting, the next step is to balance harvesting potential with the irrigation demand. IA has established many methods for calculating water demand (for example, *Irrigation, Sixth Edition*). When dealing with a sustainable rainwater harvesting system, once the water is collected, it needs to be rationed and used as effectively as possible. The need for an irrigation and management system to be highly efficient is critical.

Example 5-3
Runoff volume

Example 5-1 stated that 0.2 inches of rainfall is required to generate a day's worth of irrigation (gross requirement). Using the roof in example 5-2, the daily volume of irrigation equal to 0.2 inches of rainfall is calculated as follows:

$$V_{runoff} = 0.623 \times 0.90 \times 0.2 \times 4{,}000$$
$$= 449 \text{ gal}$$

If the irrigation system is 70 percent efficient, the net water applied to plants is

Equation 5-2
Net water needed

$$IR_{net} = IR_{gross} \times \left(\frac{IE}{100}\right)$$

where

IR_{net} = net irrigation water {gal}
IR_{gross} = gross irrigation water {gal}
IE = irrigation efficiency {%}

Example 5-3 *cont.*
Runoff volume example

$$IR_{net} = 449 \times \left(\frac{70}{100}\right)$$

$$V_{runoff} = 314 \text{ gal}$$

What if the irrigation system could be improved to 90 percent efficiency? Working backwards from the previous answer, the gross irrigation demand would be

$$IR_{net} = 449 \times \left(\frac{90}{100}\right)$$

$$V_{runoff} = 349 \text{ gal}$$

Rearranging equation 5-1, the depth of rainfall {in.} to generate 349 gallons of runoff is

$$D_R = \frac{IR_{gross}}{0.623 \times C_R \times A}$$

$$D_R = \frac{349}{0.623 \times 0.90 \times 4{,}000}$$

$$= 0.156 \text{ in.}$$

Return to the July rainwater harvesting analysis in example 5-1. If 2.4 inches of rain can be collected, how many days of irrigation from a secondary source are needed with a higher efficiency system?

31 total irrigation days (July) − 8 days of sufficient rainfall (by rain sensor) = 23 net irrigation days (July)

$$\frac{\text{2.4 in. of stored rain}}{\text{0.156 in./day of irrigation}} = \text{15.4 days of stored rainwater}$$

23 net irrigation days (July) − 15.4 days of stored rainwater = 7.6 irrigation days from secondary source (July) with higher efficiency

By increasing the efficiency of the system, the number of days requiring a secondary source dropped from 11 to 7.6 out of 31 in July (on average). Now, the costs and risks are more favorable to the end user. Reducing the irrigated area or increasing the number of drought-resistant and native plantings will further decrease reliance on the secondary source. Smart irrigation controllers and scheduling techniques are used to further improve water use and are discussed in chapter 7.

When the catchment area for harvesting is fixed, the potential water collection is fixed. The irrigation demand must be adjusted to this potential and meet the economic and risk acceptance for an owner when using alternative water.

Storage Provided

The purpose of rainwater harvesting is to collect runoff and store it for later use. Therefore, a storage device must be sized, designed, and installed so that an irrigation pump can draw water from it. The device can be anything that is watertight such as a tank or lined pond. Many other innovative storage devices such as gravel sumps, rain barrels, pillows, and even entire basements have been used, as well.

A tank is installed below ground so that runoff can be directed through piping by gravity. The tank can be made of concrete, steel, plastic, and fiberglass, which are some of the traditional materials. If the tank is watertight, there is no definitive advantage to using one material over another from a capacity standpoint. Weight, shipping, installation, and cost factor into tank selection.

An important design consideration is buoyancy. When the groundwater table is very high, tanks made from lighter materials (fiberglass, plastic, etc.) are more prone to the uplift force from buoyancy when empty than heavier materials whose weight counteracts this force. If buoyancy is a concern, additional weight (typically concrete collars or slabs) is attached to the tanks to weight them down.

Incorporating ponds for irrigation requires that they be lined and as watertight as possible. Unlike the pond in figure 3-3, which disposes water, a pond directly used for irrigation must retain as much water as possible.

When a pond is constructed for commercial projects, it is generally already part of a stormwater management system or landscape design with irrigation water being a secondary consideration. While it should be examined, pond capacity for irrigation is probably not an issue (aesthetics possibly); however, selecting an appropriate tank size is a vital step in developing an economically viable harvesting system.

Sizing a tank requires a sound understanding of the water inputs (runoff) and outputs (irrigation). If a tank is too small, then it is ineffective in providing enough harvested water for later use. If a tank is too large, the construction costs will be high and may affect the project feasibility. When performing cost analyses on different tank sizes, an economy of scale develops when, at a certain point, it no longer becomes advantageous to add more storage. Table 5-1 shows a sample method for daily tank accounting based on examples 5.1–5.3. In this table, the accounting steps are used for a proposed 2,500-gallon tank:

1. Obtain historical rainfall record.
2. Start with tank empty on day 1.
3. Determine the runoff generated each day.
4. Add the tank level and runoff.
5. Subtract out water beyond tank capacity that is overflow.
6. Determine the daily irrigation demand.
7. Use available harvested water first.
8. Subtract used harvested water from available water.
9. Use makeup water for irrigation demand differences.
10. Repeat each day and total results.

In table 5-1, a 2,500-gallon tank can collect all of the runoff generated during the month of July. Even when all the runoff is collected, rainwater harvesting may still not be enough to supply irrigation entirely (67 percent of total demand). A larger tank (e.g., 3,000 gallons) would have the same effectiveness. This demonstrates that simply installing a larger tank may not be a good solution. It is important to perform these types of analyses for many tank sizes to determine which is the most advantageous economically.

Table 5-1
Tank sizing accounting exercise

Tank = 2,500 gal Date	Rain (in.)	Tank start (gal)	+ Runoff harvest (gal)	= Subtotal (gal)	− Lost water (gal)	= Subtotal (gal)	Irrigation demand (gal)	− Harvest used (gal)	= Tank final (gal)	Makeup used (gal)
7/1	0	0	0	0	0	0	349	0	0	349
7/2	0.2	0	449	449	0	449	0	0	449	0
7/3	0	449	0	449	0	449	349	349	100	0
7/4	0	100	0	100	0	100	349	100	0	249
7/5	0.2	0	449	449	0	449	0	0	449	0
7/6	0	449	0	449	0	449	349	349	100	0
7/7	0	100	0	100	0	100	349	100	0	249
7/8	0	0	0	0	0	0	349	0	0	349
7/9	0.2	0	449	449	0	449	0	0	449	0
7/10	0.2	449	449	898	0	898	0	0	898	0
7/11	0	898	0	898	0	898	349	349	549	0
7/12	0	549	0	549	0	549	349	349	200	0
7/13	0	200	0	200	0	200	349	200	0	149
7/14	0.2	0	449	449	0	449	0	0	449	0
7/15	0	449	0	449	0	449	349	349	100	0
7/16	0	100	0	100	0	100	349	100	0	249
7/17	0	0	0	0	0	0	349	0	0	349
7/18	1.0	0	2,245	2,245	0	2,245	0	0	2,245	0
7/19	0	2,245	0	2,245	0	2,245	349	349	1,896	0
7/20	0	1,896	0	1,896	0	1,896	349	349	1,547	0
7/21	0	1,547	0	1,547	0	1,547	349	349	1,198	0
7/22	0.2	1,198	449	1,647	0	1,647	0	0	1,647	0
7/23	0	1,647	0	1,647	0	1,647	349	349	1,298	0
7/24	0	1,298	0	1,298	0	1,298	349	349	949	0
7/25	0	949	0	949	0	949	349	349	600	0
7/26	0	600	0	600	0	600	349	349	251	0
7/27	0.2	251	449	700	0	700	0	0	700	0
7/28	0	700	0	700	0	700	349	349	351	0
7/29	0	351	0	351	0	351	349	349	2	0
7/30	0	2	0	2	0	2	349	2	0	347
7/31	0	0	0	0	0	0	349	0	0	349
TOTAL	**2.4**		**5,388**		**0**		**8,027**	**5,388**		**2,639**

Marginal Analysis

It is easy to see that to spend an extra $500 on tanking each time 250 gallons of tank is added to save $1,000 on domestic water is a smart economic decision. Similarly, spending an extra $500 on tanking to save $250 on domestic water would not be a good decision. As tank sizes grow, the marginal benefit of adding storage diminishes. The point at which the marginal cost equals the marginal savings is the optimal design point for the tank size (see figs. 5-1 and 5-2).

Figure 5-1
Water harvesting potential vs. tank storage (based on table 5-1 program)

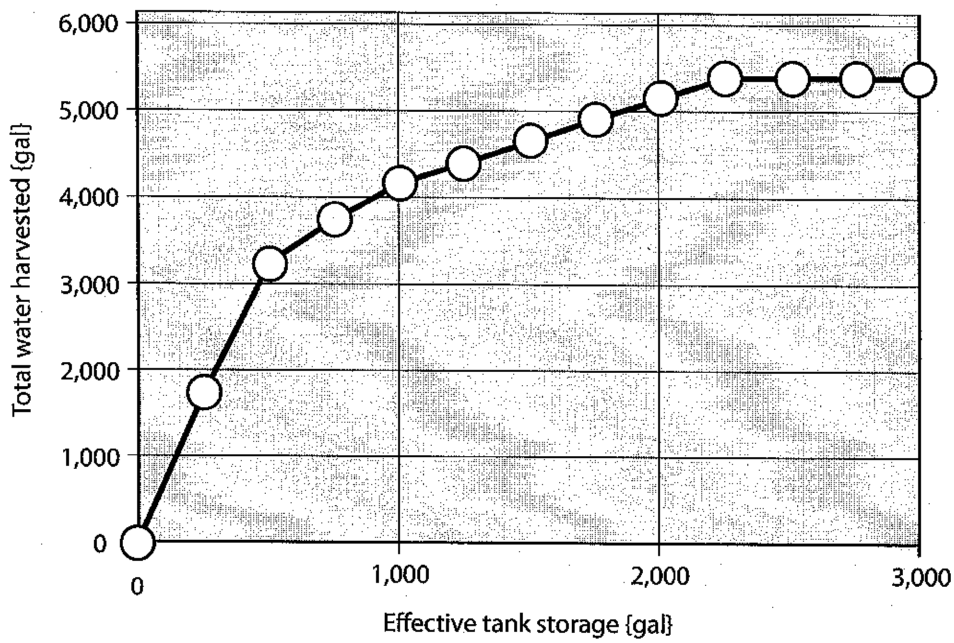


Figure 5-2
Marginal cost or benefit vs. tank storage (based on table 5-1 program)

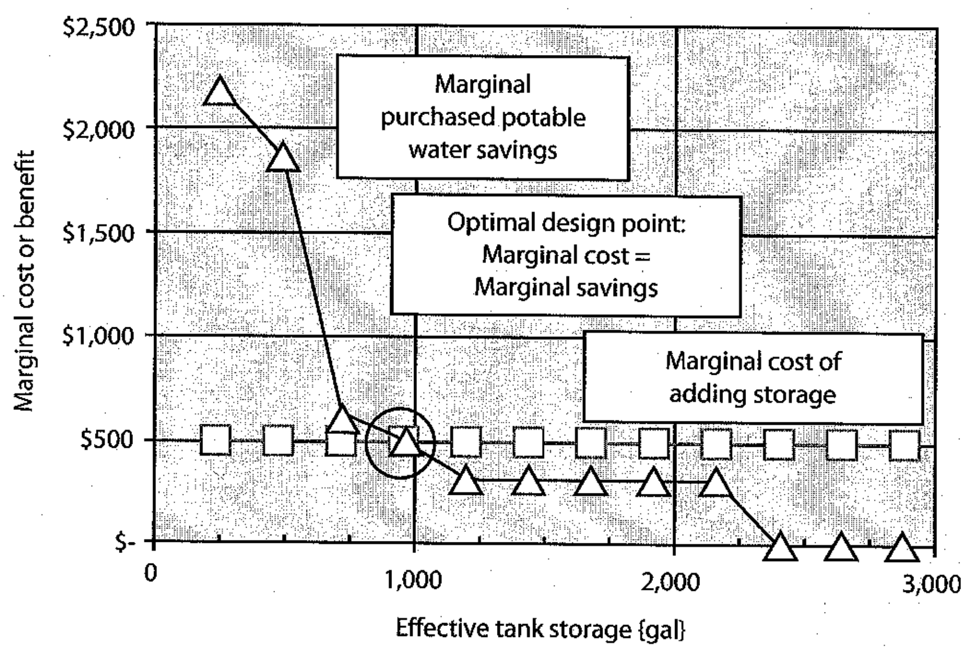


Figure 5-1 shows the result of total rainwater harvested (using the program in table 5-1) for several tank sizes. Figure 5-2 shows a hypothetical marginal cost (of adding storage) and subsequent marginal savings in purchased water. The point at which marginal cost equals marginal savings is the optimal design point (1,000 gallons in this scenario). If a 1,000-gallon tank is installed, the user will save the most money. Beyond 1,000 gallons, the costs outweigh the benefit and the user will begin to lose money (see table 5-2).

The analyses above are necessary to determine the best economic decision for tank sizing. However, this assumes that domestic water is available for purchase as a secondary makeup source. Some projects may be proposed to not use any potable water or to have a makeup source available as an option. Now, the decision on tank sizing is based on risk. Risk is an advanced concept beyond the scope of this manual, but basic assumptions or calculations can be made.

Example 5-1 determined that 11 days of secondary source irrigation was necessary. Now assume that no secondary makeup source is available. A crude estimate (based on average conditions) would be that the risk of not having enough rainwater available (either from the sky or harvested) for landscapes on any given day in July is 11 days out of 31 — or 35.5 percent. Recall example 5-3 where the irrigation system efficiency was improved from 70 to 90 percent. Only 7.6 days of makeup water were required for irrigation in July. This drops the risk to 24.5 percent. When the management allowed depletion [MAD] is factored into the calculation (as described in the IA Design Manuals), the risk drops even further.

A designer must know what the end user is seeking: an economic benefit, risk mitigation, sustainability, or a combination of them all. A sound mathematical understanding and judgment are required to size a tank properly.

Table 5-2
Marginal cost analysis for tank sizing (tank cost = $2/gal)

Analysis point	Water savings	Tank costs	Net savings/cost
Before optimal design point			
0–250 gallons	$2,200	– $500	$1,700
250–500 gallons	$1,800	– $500	$1,300
500–750 gallons	$600	– $500	$100
750–1,000 gallons	$500	– $500	$0
Total benefit/loss	**$5,100**	**– $2,000**	**$3,100**
After optimal design point			
1,000–1,250 gallons	$300	– $500	– $200
1,250–1,500 gallons	$300	– $500	– $200
1,500–1,750 gallons	$300	– $500	– $200
1,750–2,000 gallons	$300	– $500	– $200
2,000–2,250 gallons	$300	– $500	– $200
2,250–2,500 gallons	$0	– $500	$0
Total benefit/loss	**$1,500**	**–$3,000**	**– $1,500**

Regulation

Rainwater is regulated in most states from an engineering perspective: the postdevelopment condition must not generate higher runoff volumes and peak flows than the predevelopment condition. When directing runoff towards an irrigation pond or tank, it is generally welcomed by stormwater regulators as a way to reduce volume and flow leaving a site. However, a permit may be required to use captured rainwater specifically for irrigation. Regulators are typically concerned with stagnant water in ponds from a mosquito and insect larvae perspective, as well as in underground tanks with water fouling. From an environmental perspective, regulation is moderate using rainwater.

Unfortunately, in some states it is not a matter of environmental rules, but rather legal rights to runoff. Some western states have made it illegal to harvest rainwater because of the impact to downstream users. Harvesting rainwater has the potential to take out a significant amount of water available for downstream users. Review local and state law and regulation regarding water rights prior to design.

Water Quantity

As described earlier, quantity is determined by rainfall. Dependence on rainfall involves risks. Even in temperate climates, there is always a chance for extended dry periods in the summer. Water quantity is based on the four design principles of this chapter: climate, catchment area, irrigation demand, and storage provided. Rainwater harvesting is a viable method of collection only in temperate, mild climates with steady, consistent rainfall.

Note on figures 5-1 and 5-2 that the comparison is made for *effective* storage. With tanks and ponds, there are typically areas that are not available for withdrawal — either below the pump inlet (dead storage) or above the outlet (for overflow). Effective storage for ponds is dependent on design. The effective storage tanks can be anywhere from 80 to 90 percent of the total or nominal volume of the tank. With tanks, always consider effective storage and dead storage (as in fig. 5-3). Also, always provide an outlet and coordinate with the owner about where the overflow runoff should go.

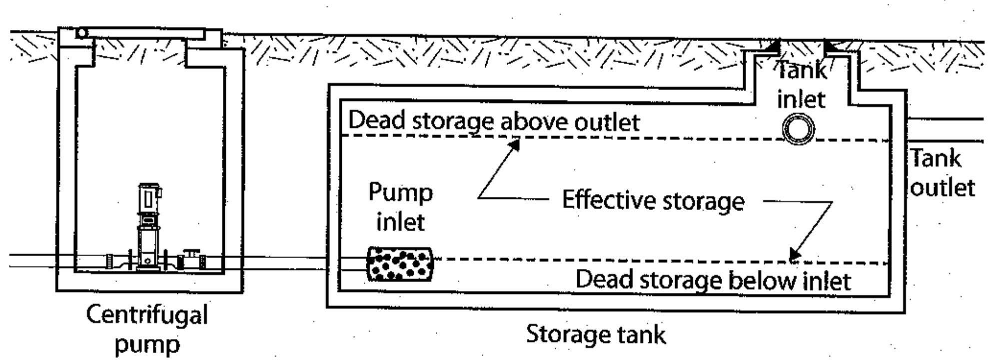


Figure 5-3
Effective tank storage based on pumping equipment and outfalls

Water Quality

Quality of rainwater is determined by the surface type and location of the catchment area used for harvesting. It can be very good if only roofs are used for collection, or it can be very poor when using parking lots or high-traffic pervious surfaces. With roofs, filtration can be minimal. Typically, a screened inlet drawing water from above the bottom of the tank is designed to keep out leaves, twigs, and nuts that may fall within a roof gutter. Depending on the irrigation system, downstream filtration may be needed. Some metallic roofing materials (such as copper) can possibly leach into rainwater and enter into a harvesting system. Consider the possible effects on plant toxicity when harvesting water from metallic roofs.

With parking lots, trash, dirt, grease, and oil are all transported in rainwater to the collection facility. It is important to work with civil and stormwater engineers to provide appropriate treatment prior to entering a pond or tank. Upstream *and* downstream filtration is necessary from these types of surfaces. Typically, a media-type filter is required to obtain an acceptable water quality level. Nonroof rainwater collected is generally low in quality, but generally usable for irrigation.

Economics

An extensive discussion on the economics of rainwater harvesting has been provided in this chapter. As shown, tanks have diminishing returns. Ponds are generally more expensive to install than tanks. However, if a pond is being constructed for stormwater volume and flow management as a mandatory part of a project design, inquire about making it a dual purpose pond by adding an irrigation pump. Rainwater harvesting is only feasible in parts of the country that have consistent, steady rainfall throughout the irrigation season.

Sometimes economic decisions are made that are not consistent with maximizing cost savings due to logistical or philosophical concerns. Potable water in some areas is not allowed for irrigation as a makeup source. The owner of a "Green" project might make the conscious decision to not use potable water for irrigation. In these cases, it becomes more prudent to harvest as much rainwater for irrigation as possible, requiring a storage size beyond the optimal design point. When potable water is not available, risk plays a greater role.

Summary

Rainwater harvesting has the potential to lessen the burden of potable water required for an irrigation system. However, there are downstream impacts to consider prior to construction. Understanding risk can provide insight to the effectiveness of a potential harvesting system. Average rainfall and collection efficiency data is useful, but it should be tempered with the understanding and knowledge of the frequency and extent of potential drought in a particular year.

Practice Questions

1. If it rains 12 times in a 30-day month with an average collection of 0.15 inches of water per event and 95 percent of the water is collected in a tank, how much water is collected that month?

SCRATCH PAD

____

2. A 1-acre roof with a ¾-inch storm event could potentially generate how much water for storage? Assume 95 percent of the water is collected.

SCRATCH PAD

____

3. The 1-acre roof with a ¾-inch storm event (from question 2) could potentially water how many square feet if the irrigation depth is 1 inch and the system is 75 percent efficient?

SCRATCH PAD

____

4. If the catchment area and surface type is fixed, what other parameter is also fixed?

5. Why does buoyancy need to be taken into account with underground storage systems?

6. Tank size is a tradeoff between what two factors?

Treated Effluent

Learning Objectives

The following objectives are the focus of chapter 6:

- differentiate between gray water and black water
- understand proper signage and coloring to mitigate health hazards
- explore how wastewater is treated and how it affects irrigation

Introductory Concepts

The term "treated effluent" is used in this chapter to categorize a group of potential water sources that would be discharged as waste back to the environment (effluent) but have been refined (treated) to the extent where they pose no significant health or environmental hazard. With regulatory agencies mounting pressure to find alternatives to potable water, reclaiming water that would otherwise be disposed of has become a viable option in some cases for landscape owners. Piping and equipment for reclaimed and other nonpotable water generally has distinct signage stating "NONPOTABLE." Purple or lavender is the accepted color for equipment that handles reclaimed water.

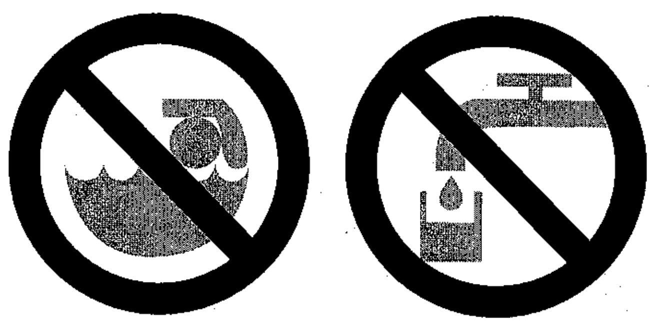
Treated effluent can be separated into two categories: human-generated effluent and machine process-generated effluent. Typical processes that generate effluent are heat exchanging (air conditioning condensate, cooling tower water) and cleaning. Human-generated effluent can be broken down further into two subcategories: gray water and black water. Gray water is generated wastewater from domestic bathing, laundry, and minor dishwashing. Black water is domestically generated wastewater from toilets, kitchen waste, and heavy cleaning with chemicals. Gray water is generally refined to the point where it does not pose a significant risk to exposure. However, it should never be ingested; it must be used immediately and with subsurface irrigation. Black water must be refined for reuse, at least to secondary but generally to tertiary treatment levels. Gray water is examined first as an alternative water source for landscape irrigation.

Gray Water

The quantity of gray water available is directly related to the number of people creating the wastewater. Small-scale projects such as residences can still use gray water, but generally it is used immediately in subsurface irrigation as a means of disposal without treatment. Gray water can be harvested for later use, but it must be treated prior to storage. While not as contaminated as black water, gray water still has enough pathogens and particles to foster bacteria growth and fouling. Temperatures are typically warm, thereby accelerating microorganism growth. Generally, untreated gray water is used in small residences within 24 hours of generation and often immediately disposed of underground.

Large-scale projects like office buildings and campuses have the potential to generate ample amounts of water suitable for irrigation. These projects may consider the cost of gray water treatment acceptable in the overall scope of landscape planning and water storage. Treated gray water can be contained in ponds or underground tanks. In either case, the storage facility must be marked clearly with signs that the water is neither potable nor for human contact (see fig. 6-1).

Figure 6-1
Typical posted warnings for reclaimed water storage and conveyance



Using gray water requires its separation from the sewer system by providing double plumbing (marked with purple and "do not drink" warning signs as in fig. 6-1). Bathroom sinks, tubs, and washing machines must be plumbed separate from toilets, kitchen sinks, and dishwashers. (Some debate on dishwasher waste exists, but it is generally considered gray water in residential applications.) This adds significant costs to projects that have to be weighed against the cost of purchasing potable water or other alternative sources. Minimal treatment of gray water includes solids removal and sand or media filtration. Gray water that is stored for extended periods is treated with media filters, UV and chlorination disinfection, and even reverse osmosis.

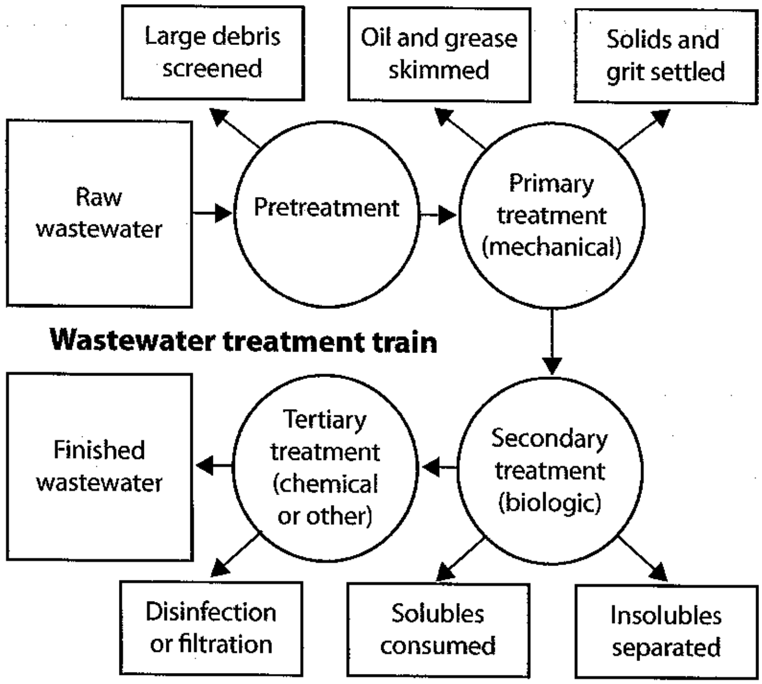
Gray water for landscapes is typically applied underground through drip irrigation. Regulatory agencies are concerned with spray irrigation of gray water; fine mist could be inhaled by people or droplets of water could come in contact with skin in high traffic areas such as landscaped developments. Agencies view gray water as "sewage" and implement rules and policies to mitigate the potential spread of disease. If gray water is used with overhead irrigation, restrictions are often put in place to minimize exposure, such as overnight irrigation only, minimum time to use landscape after application (3–6 hours) or in low-traffic areas only (spray fields, tree farms, etc.). Monthly or quarterly water quality reporting may also be required to assure the regulating body that levels of microbial pathogens (such as fecal coliform) are at acceptable levels. Agencies often may require a covenant or written agreement between landscape owner and wastewater generator (if the water is coming from off-site) for a minimum water quality standard. These agreements usually include operation and maintenance plans outlining times of transfer, minimum water quality standards, and emergency courses of action.

Even when treated as sewage, gray water can contain many harmful constituents to plant material. Salts are a major problem with gray water. Human skin contains a large amount of salt that is washed away from showers and baths. Salt accumulation increases the osmotic pressure and physical tension of soil water. Increased osmotic pressures lead to a reduction in available water for plants. Salt must be leached out with freshwater to keep osmotic pressures low. Other detrimental constituents in gray water are chlorine from bleach (laundry discharge) and boron (common ingredient in detergents, shampoos, and hand soaps). Boron in high levels is toxic to plants resulting in chlorosis, stunted branch development, and premature leaf drop. Chlorine can greatly reduce the pH balance within the soil, also affecting the plant's ability to take in water. Sewage treatment to a tertiary level (see next section) is required to remove nutrients (nitrogen and phosphorus). Mechanical methods of treatment like reverse osmosis are needed to remove most constituents from water.

Sewage Treatment

An understanding of what water quality to expect from treated sewage can be developed by knowing the major processes and steps for treatment. Figure 6-2 shows a schematic treatment train for raw sewage (black water and/or gray water). Sewage first enters a pretreatment process where large debris is screened and some of the finer particles are settled out of water. It then enters a primary treatment process that involves separating floating liquids (oils, greases, etc.) to the top and settles organic material (sludge) to the bottom in large tanks. Floating liquids are skimmed from the top and sludge is removed from the bottom, leaving water that can be refined biologically in secondary treatment. Primary treatment water is aerated so that there is sufficient oxygen for microscopic organisms (such as bacteria) to live while they consume soluble organic material and bind insoluble contaminants that can be filtered out. Separation of biological growth and settled contaminants leaves water that can be used for irrigation standards. Often, water goes through tertiary treatment that "finishes" it to a higher level of clarity. Tertiary treatment can be accomplished by clarifier ponds (lagoons), wetlands (plant intake of nutrients and other contaminants), further filtration, and/or disinfection (e.g., chlorine and ultraviolet light). Water that goes through this treatment train is usable for irrigation but is not potable. Further treatment is required.

Figure 6-2
Schematic sewage treatment train of wastewater



Reverse Osmosis

Reverse osmosis is a mechanical method of purifying water from dissolved contaminants. The most common application of reverse osmosis is desalination of seawater for drinking. However, even though it is expensive to implement, the need for clean water has made reverse osmosis a viable solution for arid and highly restricted water regions.

Osmosis is the phenomenon of flow of solvent (water) through a permeable membrane from a solution of low concentration to a solution of higher concentration. Osmosis stops when the concentrations are equal. The increase in water on the previously higher concentration column creates an osmotic pressure, [ΔP] on the wall of the membrane (see fig. 6-3a). The salinity of irrigation water will determine if water is permitted through the cell membrane to hydrate the plant (low salinity) or if water is drawn out of the cell membrane, drying out the plant (high salinity).

Reverse osmosis is a mechanical means of reversing the flow water through the membrane (see fig. 6-3b). By applying a pressure greater than ΔP, the solvent (water) can be forced through the membrane while retaining the solute (dissolved salts and other impurities). The membrane acts as a filter of dissolved contaminants. The finished product of reverse osmosis is typically very clean, potable water. The special membranes and the mechanical equipment for reverse osmosis are very expensive.

Reverse osmosis is very effective in removing impurities from wastewater. The only issue with reverse osmosis (other than high costs), is that it can be "too good" at removing constituents from water. Water from wells, streams, and even from municipal potable water contains many dissolved minerals that are actually beneficial (in moderation) to feeding plant material. Reverse osmosis strips nearly everything in the effluent. Generally, this is a good problem to have, although plant nutrition should be closely monitored.

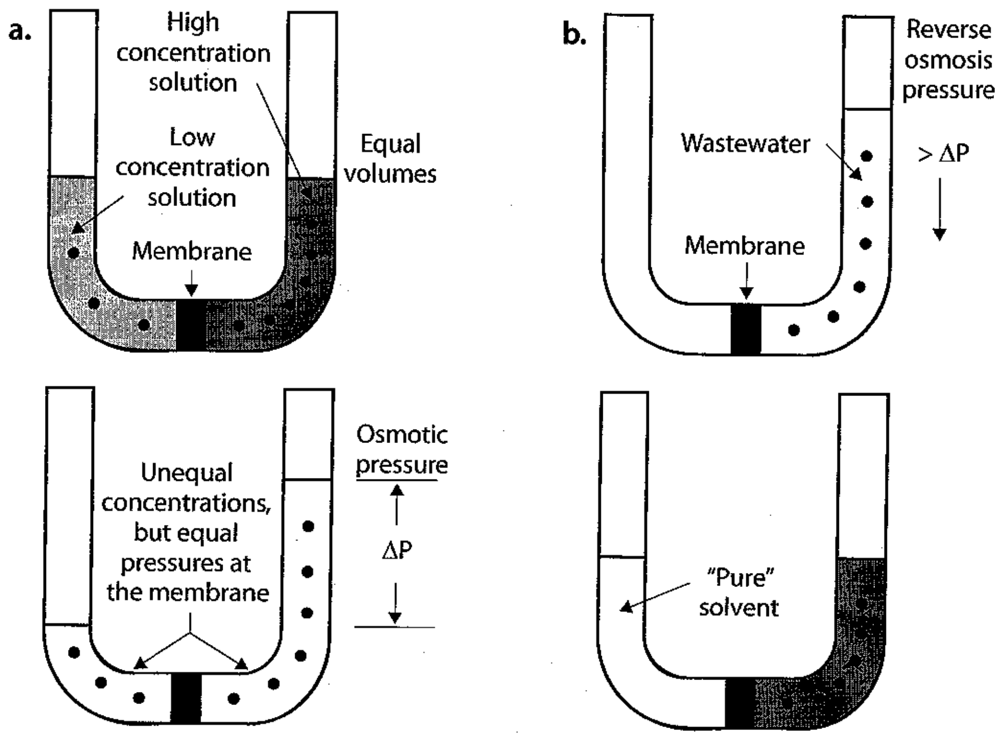


Figure 6-3
(a) Osmosis: movement of solvent (water) to equal concentrations, (b) reverse osmosis: forcing solvent only back through membrane

Condensate and Blowdown Water

Another potential irrigation source is from mechanical HVAC equipment: condensate generated from air conditioning equipment and blowdown water. In large HVAC systems, the condensate water collected from dehumidifiers and coils can be in high enough quantities to make a significant impact on potential potable water savings. Blowdown water is generated from cooling equipment and was used to flush out mineral build-up.

Condensation in and of itself would be pure water. However, as the condensation accumulates on mechanical equipment, contamination from metals and chemicals on the surface become possible. Some environmental agencies consider condensate as a potentially hazardous water source because of the threat of bacterial contamination from stagnant water in cool, dark places such as legionella (causing Legionnaire's disease). Consult local environmental and health agencies for the designation of condensate and other HVAC equipment effluent water for reuse. Chlorination or UV treatment of water prior to use for irrigation can alleviate these potential problems with fouling. Great care must be exerted when chlorinating because too much can lead to problems with plant toxicity.

Although blowdown water may be available in large quantities, it often has high salinity measured as total dissolved solids [TDS] — making it unsuitable for plants and soils. As a solvent for cleaning equipment, the waste must be monitored if it is used properly. An efficient system will be better at removing minerals on equipment and, therefore, have worse water for irrigation. However, it may be possible to dilute this water with other alternatives. Research on the allowance of both condensate and blowdown water should be conducted prior to design.

Any type of water used for heat exchange should be recooled prior to use for irrigation. Heat and hot water can be a major problem for irrigation systems. Provisions to avoid heat-related situations should be made by working with HVAC or mechanical engineers and personnel before receiving this water in tanks or ponds.

Regulation

If allowed by law, any type of treated wastewater or effluent will be heavily regulated by environmental or health agencies. Disease and sickness can be spread through wastewater readily. Microorganisms can multiply very quickly when stored in stagnation (ponds, tanks, etc.). Irrigation designers and engineers must demonstrate to these regulatory authorities that the spread of communicable diseases through sprinklers or storage will not occur. Often, regulators will ask for redundant measures to ensure safe distribution of treated water for irrigation. These redundancies will increase the cost of the system. Some states do not allow its use because of the fear of disease derived from human or machine waste.

Water Quantity

The amount of water available from treated effluent or wastewater is predicated on the amount of people or processes generating the water. Gray water from a single residence may be enough to water a small flower garden or planter bed. (Vegetable gardens are not recommended by most health agencies.) Large planned communities or campuses could generate enough wastewater to sustain an irrigation system. Careful consideration to seasonal changes in population should be made (e.g., fewer students on campus to generate wastewater in the summer).

Some municipalities offer wastewater as a utility and as an alternative to potable water. Industrial companies may seek to discharge their wastewater to those seeking water. Examining the potential for on- and off-site wastewater generation should be undertaken at the start of any treated effluent project.

Water Quality

Water quality from effluent is highly dependent on the mechanical apparatus used to treat it. However, the finished product from wastewater treatment or reverse osmosis is generally very good for irrigation. Gray water could conceivably be used directly in small applications; however, this effluent is a special case that is not generated from overly contaminated human or food waste. Regardless of the method used for treatment, this water is not potable. Storage and piping should be marked appropriately and abundantly indicating that the water in it is from reclaimed sources. Chemical treatment such as chlorination can be used to disinfect water; however, it must be used judiciously to avoid poisoning plant material. Removal or dilution of dissolved contaminants is a priority in securing a sustainable irrigation source for landscapes.

Economics

The mechanical process of treating effluent and wastewater is very expensive. If the landscape owner has to construct the infrastructure, storage, and piping for reclaimed water, the economics can adversely affect a project. However, if the landscape owner can receive treated effluent from a wastewater generator plant and receive a "tipping fee" for disposing of someone's effluent, the economics can become profitable while providing a viable water source for landscapes.

Summary

Use of treated effluent requires careful planning and consideration. While it appears to be a viable Green practice to save potable water, treated effluent is still viewed as a potential health hazard because of the chemical and biological contaminants prior to treatment. Any failure along the treatment train will result in the release of potentially harmful water to humans and wildlife. Treatment of wastewater can include a variety of mechanical, chemical, and biological methods. Provisions for redundancy and emergency must be considered. If receiving water from off-site sources, an agreement between wastewater generator and accepter must be reached to provide consistent water quantity and quality.

Practice Questions

1. What are the two types of human-generated effluent?

   (1.) ______________________________

   (2.) ______________________________

2. Gray water generated by a residence does not include waste from what household equipment/appliances?

   ____

   ____

   ____

3. What is the first step when considering using treated effluent as the water source in an irrigation system?

   ____

   ____

   ____

   ____

Chapter 7

Irrigation Controls to Mitigate & Manage Risk

Learning Objectives

The following objectives are the focus of chapter 7:

- discuss the importance of *when* water is available as compared to *how much* is available
- understand how to best mitigate water source availability problems
- highlight the advantages of "smart" controllers

The Limited Availability of Alternative Water

As mentioned in a previous chapter, a municipal or domestic potable service can provide an "unlimited" supply of water with superior quality and adequate pressure available for irrigation. In past years with domestic networks, when water was needed for irrigation, it was applied, and plants always received ample water to flourish. It is generally taken for granted that domestic water will always be available. However, municipalities and water authorities strive for responsible use of water, as well as to provide public safety. To provide fire flow, reduce capital investment or to overcome inadequate distribution systems, irrigation has become a limited use in some community-provided potable systems. Thus, alternative sources must be found.

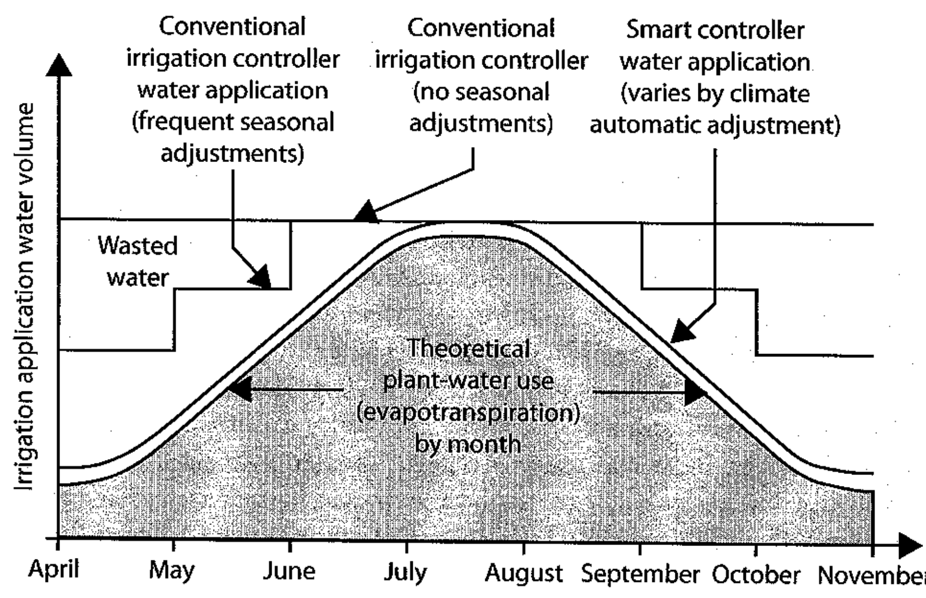
The inherent problem with alternative sources is that the desired quantity is not always available at any given time. Rainfall is sporadic, rivers rise and fall, and effluent quantities vary on generated waste. Regulators can also limit the times and quantities to collect or withdraw alternative water resources. Therefore, when dealing with alternatives sources, the goals for the irrigation designer and manager are the following:

- eliminate irrigation waste
- manage the irrigation schedule
- manage water source availability

Eliminate Irrigation Waste

Irrigation controls and management dictate the amount of water used. Barring mechanical failure, traditional automatic controls remove the risk out of missing a scheduled watering cycle. However, these controllers (set to dispense the same amount of water regardless of current climate condition) can waste considerable amounts of water. A traditional controller can be manually adjusted each season, month or week to dispense water tailored with the current climate — but this rarely happens. Smart controllers that automatically adjust irrigation run times based on daily evapotranspiration [ET], crop coefficients, or soil moisture can follow more closely the theoretical bell curve of seasonal evapotranspiration consumption. Figure 7-1 approximates the consumption of water for different controllers and scheduling against the theoretical plant water use during the year in a temperate climate. Theoretical water waste is the difference between water applied by the controller and the theoretical plant-water use curve. Reducing waste entails reducing application volumes to best approximate seasonal ET. IA has produced numerous texts, papers, and presentations about water conservation, which are recommended for reference.

Figure 7-1
Irrigation application by controller versus theoretical plant consumption



Manage Irrigation Schedule

As shown graphically in figure 7-1, the main benefit of smart controllers is their ability to make adjustments automatically. Inputs for a smart controller could be soil type, sun exposure, crop coefficient, irrigation type, etc. (see table 7-1). Both ET and soil moisture systems can make automatic adjustments and run time calculations from climate and field data. In addition, both types of systems can also employ MAD to allow a varying number of days to elapse before irrigating. The decision to irrigate can be based on a preset soil moisture level, total ET over multiple days, or both. For the purpose of the following example, assume that ET calculation and soil moisture sensing are equally effective at performing the same "smart" tasks of monitoring real time conditions and making automatic adjustments.

Smart control settings	Zone #1	Zone #2	Zone #3	Zone #4
Landscape area {ft²}	2,000	1,500	1,200	500
Soil type	Sandy loam	Sandy loam	Clay loam	Loam
Root depth {in.}	6	12	15	12
Vegetation	Turf	Shrubs	Ground cover	Mixed
Crop coefficient	0.80	0.70	0.60	0.70
Sun exposure	100%	75%	75%	50%
Irrigation efficiency	75%	90%	80%	80%

Table 7-1
Smart controller inputs by irrigation zone (possible computer interface)

Example 7-1
Sample irrigation schedule, daily replacement

A sample 8-day record of local crop evapotranspiration [ET_C] is given below (no rainfall). Based on soil properties and root depth, there is 1.50 inches of total available water for plant consumption in the soil profile. A smart controller is selected to control irrigation. Analyze the system with daily applications and for 50 percent MAD.

Date	Local ET_C {in.}	Date	Local ET_C {in.}
6/23	0.20	6/27	0.22
6/24	0.18	6/28	0.17
6/25	0.20	6/29	0.19
6/26	0.17	6/30	0.17

The first step is to compare soil moisture against the local climate record. Assume that local ET_C equals daily soil moisture depletion (not the case generally, but assumed for the purpose of this simple irrigation management illustration). Starting at field capacity on day 1, soil moisture each day is given next to the climate record. Obviously, given that the sum of local ET_C after 8 days is 1.50 inches, the plant material will die if not irrigated. Irrigation can be based on daily ET_C.

Daily ET_C irrigation schedule				
Date	Local ET_C {in.}	Initial soil moisture	Irrigation depth	Final soil moisture
Start		1.50		
6/23	0.20	1.30	0.20	1.50
6/24	0.18	1.32	0.18	1.50
6/25	0.20	1.30	0.20	1.50
6/26	0.17	1.33	0.17	1.50
6/27	0.22	1.28	0.22	1.50
6/28	0.17	1.33	0.17	1.50
6/29	0.19	1.31	0.19	1.50
6/30	0.17	1.33	0.17	1.50
TOTAL	**1.50 in.**		**1.50 in.**	

Example 7-1 *cont.*
Sample irrigation schedule, 50 percent MAD

Alternatively, irrigation can be based on MAD equal to 50 percent (0.75 inches of soil moisture reached).

MAD (50%) irrigation schedule				
Date	Local ET_c (in.)	Initial soil moisture	Irrigation depth	Final soil moisture
Start		1.50		
6/23	0.20	1.30	–	1.30
6/24	0.18	1.12	–	1.12
6/25	0.20	0.92	–	0.92
6/26	0.17	0.75	0.75	1.50
6/27	0.22	1.28	–	1.28
6/28	0.17	1.11	–	1.11
6/29	0.19	0.92	–	0.92
6/30	0.17	0.75	0.75	1.50
TOTAL	**1.50 in.**		**1.50 in.**	

Irrigation times, daily or by MAD, are adjusted to run shorter or longer based on how much water was lost to ET_C. With MAD, the irrigation system will only operate when the soil moisture falls below the preset value in the smart controller. Many days could pass before a smart controller sensor allows irrigation. However, with no rainfall, the total irrigation depth is identical in both cases (1.50 inches). A potential advantage of MAD-based systems is the possibility of rainfall between irrigation cycles to offset demand. For example, if it rained on June 29, the daily ET_C irrigation schedule might be the following.

Daily ET_c irrigation schedule					
Date	Local ET_c (in.)	Initial soil moisture	Irrigation depth	Effective rain	Final soil moisture*
Start		1.50			
6/23	0.20	1.50	0.20	–	1.50
6/24	0.18	1.50	0.18	–	1.50
6/25	0.20	1.50	0.20	–	1.50
6/26	0.17	1.50	0.17	–	1.50
6/27	0.22	1.50	0.22	–	1.50
6/28	0.17	1.50	0.17	–	1.50
6/29	0.19	1.50	–	1.00	1.50
6/30	0.17	1.50	0.17	–	1.50
TOTAL	**1.50 in.**		**1.31 in.**		

* Soils are assumed to drain to field capacity by the end of a day.

Example 7-1 *cont.*
Sample irrigation schedule, 50 percent MAD with rain

MAD (50%) irrigation schedule					
Date	Local ET_c (in.)	Initial soil moisture	Irrigation depth	Effective rain	Final soil moisture*
Start		1.50			
6/23	0.20	1.30	–	–	1.30
6/24	0.18	1.12	–	–	1.12
6/25	0.20	0.92	–	–	0.92
6/26	0.17	0.75	0.75	–	1.50
6/27	0.22	1.28	–	–	1.28
6/28	0.17	1.11	–	–	1.11
6/29	0.19	0.92	–	1.00	1.50
6/30	0.17	1.33	–	–	1.33
TOTAL	**1.50 in.**		**0.75 in.**		

* Soils are assumed to drain to field capacity by the end of a day.

If a site is fortunate enough to receive rainfall, it can reduce the overall irrigation demand — in this case, from 1.31 to 0.75 inches. However, if it does not rain, the irrigation system and water source must have the capability to apply the total required depth. Assume that 1 inch of irrigation = 10,000 gallons of irrigation in these examples. The equivalent irrigation volumes would be the following.

Date	Local ET_c (in.)	Daily ET_c irrigation (gal)	MAD = 50% irrigation (gal)
6/23	0.20	2,000	0
6/24	0.18	1,800	0
6/25	0.20	2,000	0
6/26	0.17	1,700	7,500
6/27	0.22	2,200	0
6/28	0.17	1,700	0
6/29	0.19	1,900	0
6/30	0.17	1,700	7,500
TOTAL	**1.50 in.**	**15,000 gal**	**15,000 gal**

With a daily irrigation schedule, only 1,700-2,200 gallons of water have to be available at the start of a watering window. With MAD irrigation, 7,500 gallons must be available. However, if it did rain in the same example above, the following would be the equivalent irrigation volumes.

Date	Local ET_c (in.)	Effective rain (in.)	Daily ET_c irrigation (gal)	MAD = 50% irrigation (gal)
23-Jun	0.20	–	2,000	0
24-Jun	0.18	–	1,800	0
25-Jun	0.20	–	2,000	0
26-Jun	0.17	–	1,700	7,500
27-Jun	0.22	–	2,200	0
28-Jun	0.17	–	1,700	0
29-Jun	0.19	1.00	0	0
30-Jun	0.17	–	1,700	0
TOTAL	**1.50 in.**		**13,100 gal**	**7,500 gal**

The problem with alternative water sources is that large amounts of water are not available all the time. Allowable depletion methods should be scheduled to work only when there is water available to the system. However, the water source itself can be managed and tailored to the desired irrigation schedule.

Managing Water Source Availability

When highlighting the different alternative water sources, the recurring theme from each is that physical or legislative restrictions can affect when this water is available for irrigation. Some of these obstacles can be overcome through storage, harvesting, and accumulation techniques. Combined with irrigation scheduling, it is possible to mitigate problems associated with low, restricted, and/or sporadic water availability. Table 7-2 highlights these issues.

Table 7-2
Suggested methodology for water source deficiencies

Issue	Possible solution
Low yield flow	Accumulate water prior to irrigation • Provide storage (tank or pump) • Provide separate irrigation pump Extend irrigation watering window • Reduce required irrigation flow
Time restriction	Compress irrigation schedule to restricted times • Increase pumping rate from source • Increase maximum irrigation flow Accumulate water prior to irrigation cycle • Provide storage (tank or pump) • Size separate irrigation pump to meet time restriction
Sporadic inflows	Accumulate water prior to irrigation cycle • Provide storage (tank or pump) • Provide separate irrigation pump Devise MAD plan to accommodate risk Provide backup source

Mitigating Risk

In this context, risk is the potential for water not being available for irrigating plants. After an extended period of no irrigation and no rainfall, plants will begin to wilt and possibly die. Some time can be allowed to pass between irrigation cycles to allow water stores to fill; however, too much time without watering is detrimental to landscapes. Managing water distribution is crucial to mitigating risk; it is accomplished through controls and scheduling. This becomes an exercise in managing if and when water is required (see table 7-2).

Summary

When managing an irrigation system that does not have a steady, constant supply of water, it is important to estimate not only how much water is available, but also when it is needed. Systems that do not have water available every day would not be served well with a system set to irrigate every day. Risk could be mitigated by irrigating based on the source available. Reducing and eliminating potential irrigation waste is an important first step to managing alternative water irrigation systems.

Practice Questions

1. What equipment is used to mitigate risk?

2. How are smart controllers different from conventional time-based controllers?

3. Does the frequency of watering affect the amount of storage required?

Chapter 8

Other Considerations

Learning Objectives

The following objectives are the focus of chapter 8:

- discuss the issues with mixing one or more alternatives
- review pumping concepts specific to alternative water systems
- understand and review basic permitting processes

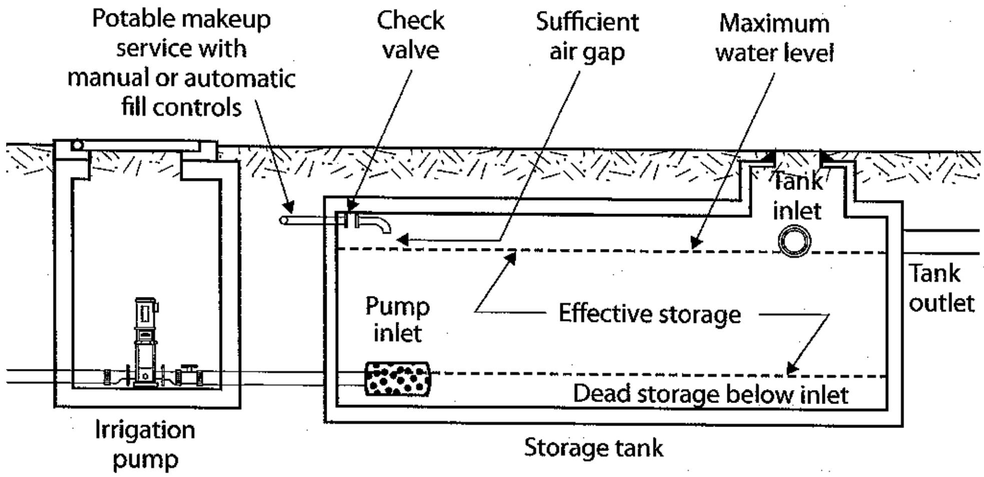
Mixing Alternatives

Multiple alternative water sources are usually available on landscaping projects. Secondary and even tertiary sources are used to supplement an otherwise unreliable primary source — like rainfall. Similar to using controls, mixing and adding multiple alternative water sources can mitigate the risk of water not being available for irrigation. In addition to maximizing water quantity, mixing alternatives can also improve water quality. For example, treated effluent with higher than desirable salt or heat levels could be mixed with purer and cooler groundwater to achieve the proper dilution and temperature.

Whenever alternatives are combined, a storage facility is required to accept both sources. Ponds or tanks can accomplish this task with a single pump supplying the irrigation system. Combinations of alternative water sources and potable water (as a makeup source or for dilution) typically are mixed at the storage facility. Depending on local plumbing codes and inspectors, separate potable and nonpotable water sources sometimes cannot be hard-piped to the same irrigation system without physically disconnecting one source and reconnecting the other with a spool piece or other backflow prevention device. In areas where simultaneous potable and nonpotable water connections are not allowed, the potable service can discharge directly into the storage facility with a sufficient air gap (see fig. 8-1). Having a storage facility that can collect all sources of water to pump from makes the most sense logistically and economically. The irrigation pump can be sized appropriately for all flows and pressures for the irrigation system from one source.

The availability of each water source must be taken into consideration. As indicated in earlier chapters, alternative water sources may be not fully reliable at any given time, or the water quality may be unacceptable. Moreover, municipalities may restrict potable water use by volume or time. A daily water balance should be made to understand how much and when water sources are available.

Figure 8-1
Potable makeup service with alternative water tank for irrigation



Pumping

Pump systems are an integral part of irrigation design with alternative water. A pump system is required because alternative water sources typically do not have the pressure requirements for irrigation (except for possibly municipal reclaimed water). Pump system design must consider the irrigation schedule and volume required (see chap. 7), as well as the pressure and flow requirements. Using a deficit-type irrigation schedule requires a larger volume per application than daily irrigation schedules. Therefore, a larger pump is necessary to fit deficit applications into a small overnight watering window. Depending on the irrigation system proposed, a pump controlled by variable frequency drive [VFD] might be an option. A VFD varies the rotational speed [RPMs] of the pump motor to provide constant pressure within the irrigation main line. If a system has a wide range of flows, a VFD can be used with greater efficiency to provide pressure for the irrigation system. In addition, varying the speed of the pump motor also varies electrical consumption. Instead of the pump motor operating at full speed and maximum power draw during irrigation, varying the RPMs lowers overall power consumption. However, for narrow flow ranges, a fixed-speed pump motor would be a more appropriate choice. With a properly selected pump curve for a narrow flow range, a VFD would serve no purpose. Pump system designs should be appropriate at conserving water, energy, and delivering the irrigation water supply in a sufficient amount of time at the proper pressure.

Filtration

As discussed in the water quality sections of each alternative source, passive filtration is typically provided prior to the pump intake. Leaves, fish, and debris must be screened from lakes and rivers while grit and other suspended solids must be filtered from treated wastewater. However, even after pumping, additional downstream filtration is usually required. Alternative water sources are often used with highly efficient irrigation systems with drip irrigation and high-performance sprinklers. Therefore, appropriate filtration from the pump discharge should accommodate efficient irrigation equipment. Mesh screening (typically to the 75-micron level) and/or media filtration (sand, stone, or synthetic particulate) can be provided. Automatic back-flushing systems are recommended to keep biological and microbial growth under control. Even with automated controls, routine maintenance of filters is crucial to long-term functionality on the entire system.

Permitting

With most alternative water sources, a permit is required for use with irrigation. As discussed previously, alternative sources are derived from natural water sources that are crucial to maintaining ecological balance or wastewater sources that could pose a health risk to people, animals, or plants. Therefore, jurisdictional authorities (environmental, planning, or health agencies) require proof that the withdrawal or use is justified and will not pose a threat to human or wildlife habitat.

The process of permitting a project varies from state to state and town to town. Typically, significant amounts of information (such as application forms, maps, and design plans) are required for the permitting agency to consider. Information is required at the time application because of legal implications. Once all of the proposal material is received, a decision could be rendered by an agency internally. When some latitude in interpreting code or law is required, a public hearing may be required so that the project can be presented for citizens to comment and express concern. These comments are intended to sway commissions toward granting leniency in interpretation or following codes strictly. Agencies and commissions that render legal decisions on projects must interpret the law consistently for all applicants; otherwise, an owner's civil rights could be violated. Knowing one's rights and the local laws where a project is proposed is critical to obtaining permits as quickly as possible.

While using alternative water is embraced by water-conscious individuals, it may not be accepted or allowed in all areas. Consultation with professionals knowledgeable of the local, state, and federal law is highly recommended.

Practice Question

1. A typical system using multiple water sources might include what alternative sources?

Managing Wet Weather with Green Infrastructure

Municipal Handbook

Rainwater Harvesting Policies

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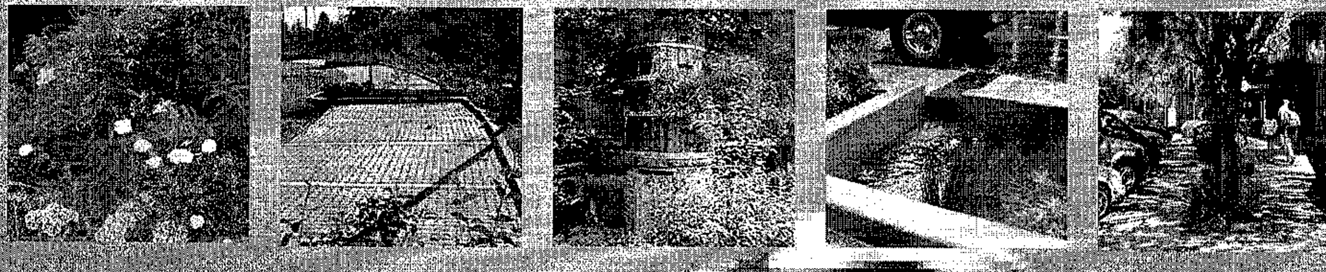

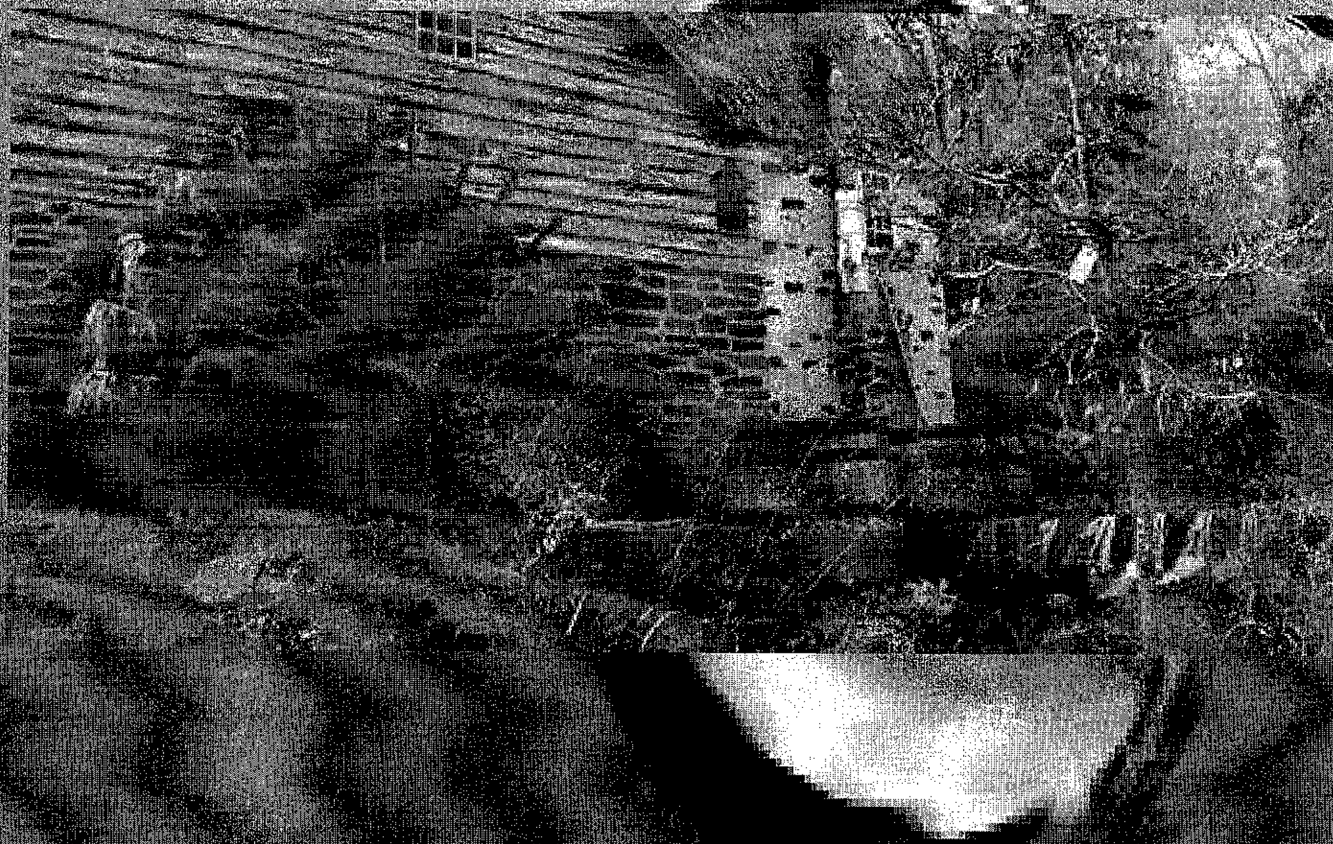

MANAGING WET WEATHER WITH GREEN INFRASTRUCTURE

MUNICIPAL HANDBOOK

RAINWATER HARVESTING POLICIES

Managing Wet Weather with Green Infrastructure

Municipal Handbook

Rainwater Harvesting Policies

prepared by

Christopher Kloss
Low Impact Development Center

The Municipal Handbook is a series of documents
to help local officials implement green infrastructure in their communities.

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Front Cover Photos
Top: rain garden; permeable pavers; rain barrel; planter; tree boxes.
Large photo: cisterns in the Wissahickon Charter School's Harmony Garden in Philadelphia

Rainwater Harvesting Policies

Introduction

From the last half of the 20th century, the U.S. has enjoyed nearly universal access to abundant supplies of potable water. But as witnessed by the recent serious and sustained droughts in the Southeast and Southwest, this past luxury is not something that can be expected for the long term. Future population growth will exert more demand on water systems while climate change is predicted to decrease available supplies because of decreased snow pack and drier regional climatic patterns. The U.S. has been identified as a country that faces imminent water shortages and a Government Accountability Office (GAO) survey found that water managers in 36 states anticipate water shortages during the first two decades of this century.[1] These challenges will require a more sustainable approach to using water resources, looking at not only how much water is used, but also the quality of water needed for each use.

The overwhelming majority of the water used in the U.S. comes from freshwater supplies of surface and groundwater. Water extracted for public systems is treated to potable standards as defined by the Safe Drinking Water Act. Access to high quality water has greatly benefited public health, but it has also resulted in our current system that utilizes potable water for virtually every end use, even when lesser quality water would be sufficient. In addition to conservation methods, using alternative sources of water will be necessary for more efficient use of water resources.

Rainwater harvesting, collecting rainwater from impervious surfaces and storing it for later use, is a technique that has been used for millennia. It has not been widely employed in industrialized societies that rely primarily on centralized water distribution systems, but with limited water resources and stormwater pollution recognized as serious problems and the emergence of green building, the role that rainwater harvesting can play for water supply is being reassessed. Rainwater reuse offers a number of benefits.[2]

- Provides inexpensive supply of water;
- Augments drinking water supplies;
- Reduces stormwater runoff and pollution;
- Reduces erosion in urban environments;
- Provides water that needs little treatment for irrigation or non-potable indoor uses;
- Helps reduce peak summer demands; and
- Helps introduce demand management for drinking water systems.

Rainwater harvesting has significant potential to provide environmental and economic benefits by reducing stormwater runoff and conserving potable water, though several barriers exist that limit its application. The U.S. uses more water per capita than any other country, with potable water delivered for the majority of domestic and commercial applications. Typical domestic indoor per capita water use, shown in Table 1, is 70 gallons per day (gpd); however outdoor water use can constitute 25% to 58% of overall domestic demand, increasing per capita domestic use up to 165 gpd.

Table 1. Typical Domestic Daily per Capita Water Use.[3]

Use	Gallons per Capita	% of Daily Total
Potable indoor uses		
• Showers	11.6	7.0%
• Dishwashers	1.0	0.6%
• Baths	1.2	0.8%
• Faucets	10.9	6.6%
• Other uses, leaks	11.1	6.7%
Subtotal	**35.8**	**21.7%**
Non-potable indoor uses		
• Clothes washers	15.0	9.1%
• Toilets	18.5	11.2%
Subtotal	**33.5**	**20.3%**
Outdoor uses	**95.7**	**58.0%**

While potable water is used almost exclusively for domestic uses, almost 80% of demand does not require drinkable water. Similar trends exist for commercial water use. Table 2 provides examples of daily commercial water usage.

Table 2. Typical Daily Water Use for Office Buildings and Hotels.[4]

Use	**Office Buildings** **% of Daily Total**	**Hotels** **% of Daily Total**
Potable indoor uses		
Showers	---	27%
• Faucets	1%	1%
• Kitchen	3%	10%
• Other uses	10%	19%
Subtotal	**14%**	**57%**
Non-potable indoor uses		
• Toilets/urinals	25%	9%
• Laundry	---	14%
• Cooling	23%	10%
Subtotal	**48%**	**33%**
Outdoor uses	**38%**	**10%**

Both the domestic and commercial water use statistics show that potable water is often being utilized for end uses that could be satisfied with lesser quality water. The statistics also indicate that nearly all water is used in a one-time pass through manner, with little attempt at reuse. Rainwater harvesting offers an alternative water supply that can more appropriately match water use to the quality of water supplied.

Rainwater harvesting systems typically divert and store runoff from residential and commercial roofs. Often referred to as 'clean' runoff, roof runoff does contain pollutants (metals or hydrocarbons from roofing materials, nutrients from atmospheric deposition, bacteria from bird droppings), but they are generally in lower concentrations and absent many of the toxics present in runoff from other impervious surfaces. Installing a rainwater collection system requires diverting roof downspouts to cisterns or rain barrels to capture and store the runoff. Collection containers are constructed of dark materials or buried to prevent light penetration and the growth of algae.[5] From the storage container, a dual plumbing system is needed for indoor uses and/or a connection to the outdoor irrigation system.

Regulations

Although a few states and local jurisdictions have developed standards or guidelines for rainwater harvesting, it is largely unaddressed by regulations and codes. Neither the Uniform Plumbing Code

(UPC) nor International Plumbing Code (IPC) directly address rainwater harvesting in their potable or stormwater sections. Other reuse waters are covered by codes. The UPC's Appendix J addresses reclaimed water use for water closets and urinals and the IPC's Appendix C addresses graywater use for water closets and urinals along with subsurface irrigation.[6] Both sections focus on treatment requirements, measures necessary to prevent cross-contamination with potable water, and appropriate signage and system labeling. However, because of a general lack of specific rainwater harvesting guidance some jurisdictions have regulated harvested rainwater as reclaimed water, resulting in more stringent requirements than necessary. These issues have led to confusion as to what constitutes harvested rainwater, graywater, or reclaimed water.[7]

The confusion among waters for reuse and the lack of uniform national guidance has resulted in differing use and treatment guidelines among state and local governments and presents an impediment to rainwater reuse. Texas promotes harvested rainwater for any use including potable uses provided appropriate treatment is installed; Portland, like many other jurisdictions, generally recommends rainwater use to the non-potable applications of irrigation, hose bibbs, water closets, and urinals.

UPC Definitions – Waters for Reuse[8]

- *Graywater* – untreated wastewater that has not come in to contact with black water (sewage). Graywater includes used water from bathtubs, showers, lavatories, and water from clothes washing machines.
- *Reclaimed water* – water treated to domestic wastewater tertiary standards by a public agency suitable for a controlled use, including supply to water closets, urinals, and trap seal primers for floor drains and floor sinks. Reclaimed water is conveyed in purple pipes (California's purple pipe system is one of the better known water reclamation systems).
- *Harvested rainwater* – stormwater that is conveyed from a building roof, stored in a cistern and disinfected and filtered before being used for toilet flushing. It can also be used for landscape irrigation.

To develop general or national guidance for rainwater harvesting, several factors must be considered. While potable use is possible for harvested rainwater, necessary on-site treatment and perceived public health concerns will likely limit the quantity of rainwater used for potable demands. Irrigation and the non-potable uses of water closets, urinals and HVAC make-up are the end uses that are generally the best match for harvested rainwater. A lesser amount of on-site treatment is required for these uses and, as seen from the use statistics presented above, these uses constitute a significant portion of residential and commercial demand. Focusing harvested rainwater on irrigation and selected non-potable indoor uses can significantly lower demand while allowing a balance and public comfort level between municipal potable water and reused rainwater.

Guidance for the reuse of harvested stormwater will be similar to reclaimed water and graywater but will differ because of lower levels of initial contamination and targeted end uses. The primary concerns of indoor rainwater reuse are cross-contamination of the potable supply and human contact with bacteria or pathogens that may be present in the collected rainwater. Portland's Rainwater Harvesting One and Two Family Dwelling Specialty Code provides a good example of specific rainwater reuse stipulations. Although the code doesn't address multi-family residential or non-residential applications, rainwater reuse is permitted for these facilities, but due to the unique design of each system, commercial reuse systems are considered on a case by case basis. In addition, multi-family residential units and sleeping portions of hotels are allowed to use rainwater for irrigation only; non-residential buildings are permitted to use rainwater for irrigation, water features, water closets and urinals. In these applications, water provided for water closets and urinals must be treated with filters and UV and/or chlorinating.[9]

Tucson Rainwater Harvesting Requirements

Tucson, Arizona became the first city in the country to require rainwater harvesting for landscaping use. Beginning June 1, 2010, 50% of a commercial property's irrigation water must be supplied from rainwater. In addition to cisterns, the regulations allow berms and contoured slopes to be used to direct rainwater to trees and landscaped areas.

Portland's code permits rainwater reuse for potable uses at family dwellings only through an appeals process. In addition, rainwater used only for outdoor irrigation is not covered by the code and needs no treatment prior to use. Acceptable indoor non-potable uses are hose bibbs, water closets, and urinals. The code illuminates several important issues that need to be considered when developing rainwater harvesting code.

Excerpts of General Requirements
Portland Rainwater Harvesting Code Guide

General

- Harvested rainwater may only be used for water closets, urinals, hose bibbs, and irrigation.
- Rainwater can only be harvested from roof surfaces.
- The first 10 gallons of roof runoff during any rain event needs to be diverted away from the cistern to an Office of Planning & Development Review (OPDR) approved location.

Rainwater Harvesting System Components

- Gutters – All gutters leading to the cistern require leaf screens with openings no larger than 0.5 inches across their entire length including the downspout opening.
- Roof washers – Rainwater harvesting systems collecting water from impervious roofs are required to have a roof washer for each cistern. Roof washers are not required for water collected from green roofs or other pervious surfaces. The roof washer is required to divert at least the first 10 gallons of rainfall away from the cistern and contain 18 inches of sand, filter fabric, and 6 inches of pea gravel to ensure proper filtration.
- Cisterns – Material of construction shall be rated for potable water use. Cisterns shall be able to be filled with rainwater and the municipal water system. Cross-contamination of the municipal water system shall be prevented by the use of (1) a reduced pressure backflow assembly or (2) an air gap. Cisterns shall be protected from direct sunlight.
- Piping – Piping for rainwater harvesting systems shall be separate from and shall not include any direct connection to any potable water piping. Rainwater harvesting pipe shall be purple in color and labeled "CAUTION: RECLAIMED WATER, DO NOT DRINK" every four feet in length and not less than once per room.
- Labeling – Every water closet or urinal supply, hose bibb or irrigation outlet shall be permanently identified with an indelibly marked placard stating: "CAUTION: RECLAIMED WATER, DO NOT DRINK."
- Inspections – Inspections are required of all elements prior to being covered.
- Maintenance – Property owner is responsible for all maintenance.

- *Water quality* – Water quality and its impact on human health is a primary concern with rainwater harvesting. This issue is comprised of two components: end use of the rainwater and treatment provided. Rainwater used for residential irrigation (on the scale of rain barrel collection) does not typically require treatment. Commercial applications and non-potable indoor uses require treatment but the type of use will determine the extent of treatment. Each jurisdiction will need to assess the level of treatment with which it is comfortable, but limiting rainwater reuse to water closets, urinals and hose bibbs presents little human health risk. Each system will require some level of screening and filtration to prevent particles and debris from traveling through the plumbing system, and most jurisdictions require disinfection with UV or chlorination because of bacterial concerns. Table 3 provides an example of minimum water quality guidelines and suggested treatment methods for collected rainwater.

  A review of treatment standards among various jurisdictions shows a wide range of requirements from minimal treatment to reclaimed water standards. A recent memorandum of understanding from the City and County of San Francisco allows rainwater to be used for toilet flushing without being treated to potable standards. Texas requires filtration and disinfection for non-potable indoor uses, and Portland requires filtration for residential non-potable indoor uses, but requires filtration and disinfection for multi-family and commercial applications. Treatment requirements ultimately come down to risk exposure with risk of bacterial exposure determining the most stringent levels of treatment. However, San Francisco's Memorandum or Understanding indicates a belief in a low exposure risk with rainwater when used for toilet flushing. Likewise, testing conducted in Germany demonstrated that the risk of *E. coli* contact with the human mouth from toilet flushing was virtually non-existent, resulting in the recommendation that special disinfection measures were unnecessary for rainwater dedicated to non-potable uses.[10]

The level of treatment required by each municipality can influence the number of harvesting systems installed. Filtration and disinfection are not expensive treatment requirements but each treatment requirement adds a cost to the system. Simplifying the treatment requirements when there is not a threat to public health lowers the cost for private entities to install systems and encourages broader adoption of the practice.

- *Cross-contamination* – Cross-contamination of the potable water system is a critical concern for any water reuse system. Cross-contamination measures for rainwater reuse systems will be similar to those for reclaimed and graywater systems. When rainwater is integrated as a significant supply source for a non-potable indoor use, a potable make-up supply line is needed for dry periods and when the collected rainwater supply is unable to meet water demands. The make-up supply to the cistern is the point of greatest risk for cross-contamination of the potable supply. Codes will require a backflow prevention assembly on the potable water supply line, an air gap, or both. In addition to backflow prevention, the use of a designated, dual piping system is also necessary. Purple pipes, indicating reused water, are most often used to convey rainwater and are accompanied by pipe stenciling and point-of-contact signage that indicates the water is non-potable and not for consumption.
- *Maintenance and inspection* – The operation and maintenance of rainwater harvesting systems is the responsibility of the property owner. Municipal inspections occur during installation and inspections of backflow prevention systems are recommended on an annual basis. For the property owner, the operation of a rainwater harvesting system is similar to a private well. Especially for indoor uses annual water testing to verify water quality is recommended as well as regular interval maintenance to replace treatment system components such as filters or UV lights. The adoption and use of rainwater harvesting systems will add to the inspection responsibilities of the municipal public works department, but the type of inspection, level of effort, and documentation required will be similar to those of private potable water systems and should be readily integrated into the routine of the inspection department.

Table 3. Minimum Water Quality Guidelines and Treatment Options for Stormwater Reuse.[11]

Use	Minimum Water Quality Guidelines	Suggested Treatment Options
Potable indoor uses	• Total coliforms – 0 • Fecal coliforms – 0 • Protozoan cysts – 0 • Viruses – 0 • Turbidity < 1 NTU	• Pre-filtration – first flush diverter • Cartridge filtration – 3 micron sediment filter followed by 3 micron activated carbon filter • Disinfection – chlorine residual of 0.2 ppm or UV disinfection
Non-potable indoor uses	• Total coliforms < 500 cfu per 100 mL • Fecal coliforms < 100 cfu per 100 mL	• Pre-filtration – first flush diverter • Cartridge filtration – 5 micron sediment filter • Disinfection – chlorination with household bleach or UV disinfection
Outdoor uses	N/A	Pre-filtration – first flush diverter

*cfu – colony forming units
*NTU – nephelometric turbidity units

Institution Issues and Barriers

Although stormwater reuse offers environmental and economic benefits, its use has remained relatively limited. This is caused by a number of perceived and actual barriers. The high rate of water consumption in the U.S. is coupled with water cost rates that are among the lowest. For example, U.S. water use is approximately twice that of Europe, but the annual cost of household water bills are roughly equal. The cost of water in the U.S. ranges from $0.70 to $4 per thousand gallons, with the national average cost slightly more than $2 for a thousand gallons. Price, therefore, creates little incentive for conservation or the use of alternative sources.[12]

Residential rain barrels are an inexpensive and easy retrofit that reduces stormwater runoff and provides irrigation water. *Photo at left: District of Columbia Water & Sewer Authority; Photo at right: Ann English.*

San Francisco Rainwater Harvesting MOU

In 2008, San Francisco's Public Utilities Commission (SFPUC), Department of Building Inspection (DBI), and Department of Public Health (DPH) signed a Memorandum of Understanding for the permitting requirements for rainwater harvesting systems located within the City and County of San Francisco. The MOU encourages rainwater harvesting and its reuse for non-potable applications without requiring treatment to potable water standards. It also defines the roles of the participating agencies. From the MOU:

- The SFPUC will create and distribute guidance and material on rainwater harvesting. The material will cover system design, system components, allowable uses, owner responsibilities, and permitting requirements. The SFPUC will encourage all rainwater harvesters to notify the SFPUC with the design specifications of their systems for research purposes.
- DBI will issue permits for construction of properly designed rainwater harvesting systems for non-potable uses that meet the minimum criteria described in the MOU and in guidance materials prepared by the SFPUC. DBI will be responsible for review of permit applications and inspection of rainwater harvesting systems that require permits.
- DPH will review rainwater harvesting projects that propose any residential indoor uses of rainwater other than toilet flushing to assure the protection of public health.

It also stipulates that system design, maintenance, and use are the responsibility of the system owner.

The MOU classifies rain barrels and cisterns and defines the allowable uses of harvested rainwater. Water from rain barrels may be used for irrigation and vehicle washing; it is prohibited to connect rain barrels to indoor or outdoor plumbing. Water from cisterns connected to indoor plumbing may be used for irrigation, vehicle washing, heating and cooling, and toilet flushing. If a cistern is not connected to indoor plumbing it cannot be used for toilet flushing.

The MOU also includes safety and maintenance requirements, required system components, labeling requirements, and DBI permit requirements.

To better manage natural resources and water infrastructure, EPA has advocated four pillars of sustainable infrastructure, one of which is full cost pricing of water. Full cost pricing would result in water rates that reflect the entire suite of costs associated with water delivery: past, present, and future capital costs and operations and maintenance. Full cost pricing would ideally also include the external costs associated with the environmental damage and resource depletion created by water use.[13, 14] However, user fees and other funding sources are insufficient in 29% of water utilities to cover the cost of providing service, let alone including external costs.[15] Insufficient pricing is a significant barrier to collection and reuse.

Water needed for sanitation, cleaning, and cooking is less responsive to price than discretionary uses such as landscaping, but overall, water generally displays inelastic demand. A 10% increase in domestic prices decreases demand 2 to 4%; a 10% increase in commercial prices decreases demand 5 to 8%.[16] While studies show that price has limited effect on demand, they also do not consider the option of a low-cost alternative source of water. Increased prices may not significantly diminish water use, but may be sufficient to encourage the use of lower cost alternatives. When faced with sufficiently priced potable water, the investment in a low cost alternative that provides continued savings becomes increasingly favorable.

Albuquerque-Bernalillo County Building Standards

In 2008, the Water Utility Authority of Albuquerque-Bernalillo County instituted new standards that require rainwater harvesting systems for new homes. Buildings larger than 2,500 square feet are required to have a cistern and pump, while smaller buildings can use cisterns, rain barrels, or catchment basins. All rainwater harvesting systems need to capture the runoff from at least 85% of the roof area.

The standards also include a requirement for high efficiency toilets and prohibitions against installing turf on slopes steeper than 5:1 and sprinkler irrigating areas smaller than 10 feet in any dimension.

Regulations and codes also inhibit rainwater collection. Plumbing codes have been identified as a common barrier. Whether they make no provisions for rainwater reuse or require downspouts to be connected to the stormwater collection system, thereby eliminating the possibility of intervening to intercept roof runoff, code changes are often a necessary first step to enabling rainwater harvesting. Other regulations complicate the implementation of rainwater harvesting. Western water rights and the doctrine of "first in time, first in line" access to water can present a barrier to rainwater harvesting. Colorado interprets its Western water rights laws as prohibiting rainwater harvesting. The state's interpretation that cisterns and rain barrels prevent runoff from reaching rivers and thereby decrease a downstream user's allotted water right has been questioned, but it currently prohibits rainwater capture and reuse.

Rainwater Harvesting in the West

Western water rights can be an impediment to rainwater harvesting efforts because the doctrine of prior appropriation has created ambiguity about the legality of intercepting and storing rainwater. In the strictest interpretation, diverting rainwater to a collection system is a taking of a water previously appropriated.

This issue has been overlooked for many community rain barrel initiatives, because the individual storage units are relatively small. The City of Seattle, however, obtained a citywide water-right permit to ensure the legality of water harvesting efforts.

State legislation may ultimately be necessary to ensure the legality of rainwater harvesting and establish the upper capacity limit for rainwater systems. Any efforts should fully assess the watershed impacts of rainwater harvesting efforts. Colorado law, for instance has assumed that all rainfall eventually reaches groundwater or surface waters and is therefore appropriated. In the dry regions of the state, however, a study has found that the majority of rainfall on undeveloped lands is lost to evaporation and transpiration and only a small fraction actually reaches surface waters.

Likewise, rainwater harvesting is a water conservation practice which will reduce the overall withdrawal and use of water, making a greater quantity of water available for downstream users. Harvested rainwater used for irrigation or other outdoor uses reapplies the water in a manner similar to normal precipitation. Rainwater used for non-potable indoor uses is collected in the sanitary system and eventually returned to receiving streams and available for downstream use.

Energy and Climate

In addition to the natural resources impacts that water use imparts, water collection, treatment, and distribution has energy and climate consequences. The connection between water and energy is often overlooked but the process of extracting water from surface or groundwater supplies, bringing it to treatment facilities, treating it to drinking water standards, and delivering it to residential and commercial customers expends energy primarily because of pumping and treatment costs. The water sector consumes 3% of the electricity generated in the U.S. and electricity accounts for approximately one-third of utilities' operating costs.[17] Reducing potable water demand by 10% could save approximately 300 billion kilowatt-hours of energy each year.[18] Water reuse systems, like rainwater harvesting, supplant potable water and reduce demand. The reduced water demand provided by rainwater harvesting systems translates directly to energy savings. Table 4 presents estimates of the energy required to deliver potable water to consumers.

Table 4. Estimated Energy Consumption for Water Treatment and Distribution.[19]

Activity	Energy Consumption kWh/MG
Supply and conveyance	150
Water Treatment	100
Distribution	1,200
Total	**1,450**

Decreasing potable water demand by 1 million gallons can reduce electricity use by nearly 1,500 kWh. An inch of rainfall produces 600 gallons of runoff per 1,000 square feet of roof. Coordinated residential applications and large-scale non-residential rainwater harvesting systems offer an alternative method of reducing energy use.

Limiting energy demand is significant but the impact that decreased energy demand has on carbon dioxide emissions is critical. Carbon dioxide emissions associated with electricity generation vary according to the fossil fuel source. Rough estimates suggest that reducing potable water demand by 1 million gallons can reduce carbon dioxide emissions 1 to 1½ tons when fossil fuels are used for power generation (Table 5).

Table 5. Carbon Dioxide Emissions from Electric Power Generation.[20]

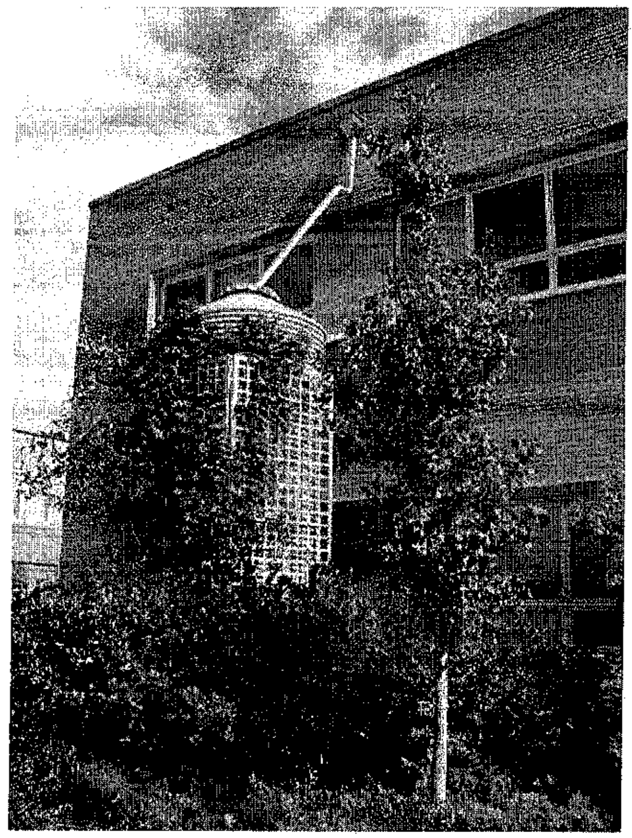
Fuel Type	CO_2 Output Rate Pounds CO_2/kWh	CO_2 Output per MG Water Delivered (x 1,450 kWh)
Coal	2.117	3,070 lbs
Petroleum	1.915	2,775 lbs
Natural gas	1.314	1,905 lbs

The carbon reductions associated with rainwater harvesting are admittedly not on the order of magnitude required to significantly impact climate change. However, the connection between potable water use and energy demand is important to recognize in the broader context of sustainable water management. It is critical to assess water use not only from a resource availability and protection standpoint, but also with the aim of improving overall sustainability of which energy is a critical component. As municipalities are faced with the anticipated CO_2 reductions that will be required over the coming decades, decreased potable water demand (along with other measures such as increased energy efficiency and conservation) represent the "low hanging fruit" that may provide the quickest and easiest reductions. Rainwater harvesting along with graywater and reclaimed water reuse represent an integrated water management approach that can not only limit contributions to climate change, but also protect and conserve limited water resources developing resiliency to the uncertain effects of climate change.

Conclusions and Recommendations

Encouraging rainwater harvesting and reuse requires enabling the practice through codes and regulations and providing incentives. State or municipal codes need to address public health concerns by stipulating water quality and cross-contamination requirements. Similar to reclaimed and graywater, specific rainwater harvesting codes need to be developed. Codes should establish acceptable uses for rainwater and corresponding treatment requirements. Disinfection of rainwater for reuse has been the standard, but recent research and policies should encourage jurisdictions to evaluate lesser requirements for non-potable uses in water closets and urinals. The simplification of the on-site treatment process and associated cost savings could broaden the use of rainwater harvesting without increasing exposure risks.

In addition to code development, incentives for rainwater harvesting should be instituted. The incentives should recognize that rainwater is a resource and that the use of potable water carries and environmental and economic cost. Current water policies and rates do not promote sustainability, with a structure that inadequately accounts for the value of water and does not promote conservation. Municipalities should review their water rates to see if they appropriately account for the full cost of water. Pricing alternatives such as increasing block rates, which increase the price of water with increased use, create an incentive to conserve potable water. An increased price of potable water would encourage investment in rainwater harvesting systems because they offer a long-term inexpensive supply of water after the initial capital investment. The combined actions of establishing certain requirements for rainwater harvesting systems and increasing the currently underpriced cost of water creates a complementary system that can encourage the use of alternative water sources.



Commercially sized cistern at the Chicago Center for Green Technology. *Photo: Abby Hall, EPA.*

Considerations when Establishing a Municipal Rainwater Harvesting Program

1. Establish specific codes or regulations for rainwater harvesting
   - Building and plumbing codes are largely silent on rainwater harvesting. Consequently, graywater requirements are often used to govern rainwater harvesting systems, resulting in requirements that are more stringent than necessary. Codes should define rainwater harvesting and establish its position as an acceptable stormwater management/water conservation practice.
2. Identify acceptable end uses and treatment standards
   - Each municipality will need to consider and identify acceptable uses for harvested rainwater and the required treatment for specified uses. Rainwater is most commonly used for non-potable applications and segregated by indoor and outdoor uses.
     - Typical outdoor uses:
       1. Irrigation; and
       2. Vehicle washing.
     - Typical indoor uses:
       1. Toilet flushing;
       2. Heating and cooling; and
       3. Equipment washing.
   - Non-potable uses typically require minimal treatment. Outdoor uses normally need only prescreening to limit fouling of the collection system. Indoor non-potable uses do not necessarily require treatment beyond screening, although some municipalities have adopted a conservative approach and require filtration and disinfection prior to reuse.
   - Harvested rainwater can be used for potable applications although a special permitting process should be established to ensure that proper treatment (e.g., filtration and disinfection) is provided and maintained.
3. Detail required system components
   - Jurisdictions often delineate between rain barrels and cisterns because of the size and potential complexity of the systems. Rain barrels collect relatively small quantities of water and generally only require mosquito prevention, proper overflow, and an outlet for outdoor uses. Cisterns can be 100 to several thousand gallons in size and may be connected to various indoor plumbing and mechanical systems. Needed system requirements include:
     - Pre-filtration – Filtration prior to the rain barrel or cistern should be provided to remove solids and debris.
     - Storage containers – Rain barrels and cisterns should be constructed of a National Sanitation Foundation approved storage container listed for potable water use.
     - Back-flow prevention – For cisterns that require a potable water make-up for operation, back flow prevention in the form of an air gap or backflow assembly must be provided.
     - Duel piping system – a separate piping system must be provided for harvested rainwater distribution. The pipe should be labeled and color coded to indicate non-potable water. Purple piping indicating reclaimed water is often used for rainwater harvesting systems. Cross connections with the potable water supply system are prohibited.
     - Signage – permanent signage should be provided at every outlet and point of contact indicating non-potable water not for consumption. In addition, biodegradable dyes can be injected to indicate non-potable water.
4. Permitting
   - Rain barrels should not need to be permitted provided that they are installed correctly and direct overflow to a proper location. A permit application process should be instituted for cistern systems used for non-potable uses. If harvested rainwater is used for potable water, the collection and treatment system should be inspected and approved by the public health department.
5. Maintenance
   - Adequate design and maintenance of the cistern and piping system is the responsibility of the cistern owner.
6. Rates of reuse
   - For harvesting systems to be efficient stormwater retention systems, the collected rainwater needs to be used in a timely matter to ensure maximum storage capacity for subsequent rain events. Cistern systems generally supply uses with significant demands, ensuring timely usage of the collected water. Outreach and education is a critical component of rain barrel programs, however, because of the more episodic and less structured use of this collected water. Municipalities should inform homeowners of the steps needed to maximize the effectiveness of their rain barrels. Harvesting programs targeting susceptible combined sewer areas have used slow draw down of the rain barrels to delay stormwater release to the sewer system, yet ensure maximum storage capacity for subsequent rain events.

Case Studies

King Street Center, Seattle

The King Street Center in Seattle uses rainwater for toilet flushing and irrigation. Rainwater from the building's roof is collected in three 5,400 gallon cisterns. Collected rainwater passes through each tank and is filtered prior to being pumped to the building's toilets or irrigation system through a separate piping system. When needed, potable makeup water is added to the cisterns. The collection and reuse system is able to provide 60% of the annual water needed for toilet flushing, conserving approximately 1.4 million gallons of potable water each year.[21]

The Solaire, Battery Park City, New York

The 357,000 square foot, 27 floor building was the first high-rise residential structure to receive LEED® Gold certification. The Solaire was designed to comply with Battery Park City's progressive water and stormwater standards; more than 2 inches of stormwater must be treated on site to meet the standards. Rainwater is collected in a 10,000 gallon cistern located in the building's basement. Collected water is treated with a sand filter and chlorinated according to New York City Standards prior to being reused for irrigating two green roofs on the building. Treated and recycled blackwater is used for toilet flushing and make-up water. Water efficient appliances and the rainwater and blackwater reuse system have decreased potable water use in the building by 50%.[22] Because of its innovative environmental features, the Solaire earned New York State's first-ever tax credit for sustainable construction.[23, 24]

Philip Merrill Building, Annapolis, MD

The Chesapeake Bay Foundation's headquarters is a LEED® Version 1 Platinum certified building. Rainwater from the roof is collected in three exposed cisterns located above the entrance.[25] Roof runoff passes through roof washers before entering the cisterns; following the cisterns the water is treated with a sand filter, chlorination, static mixer, and carbon filter prior to reuse. The building uses composting toilets, so the reused water is used for bathroom and mop sinks, gear washing, irrigation, fire suppression, and laundry. The building's design allows for a 90% reduction in potable water use with 73% of the water used within the building supplied by the cistern collection system.[26, 27, 28]

Cisterns at CBF headquarters. Photo: *Chesapeake Bay Foundation.*

Alberici Corporate Headquarters, Overland, Missouri

Alberici Corporation, a construction company, chose to relocate its corporate headquarters to a 14-acre site in the St. Louis suburbs in 2004. The site renovation included refurbishing a 150,000 square foot former metal fabrication facility into a LEED® platinum certified office building. The building design includes a rainwater collection and reuse system. Rainwater is collected from 60% of the garage roof area and stored in a 38,000 gallon cistern. The collected water is filtered and chlorinated and used for toilet flushing and the building's cooling tower. The stormwater reuse system saves 500,000 gallons of water each year, reducing potable water demand by 70%.[29, 30]

Lazarus Building, Columbus, Ohio

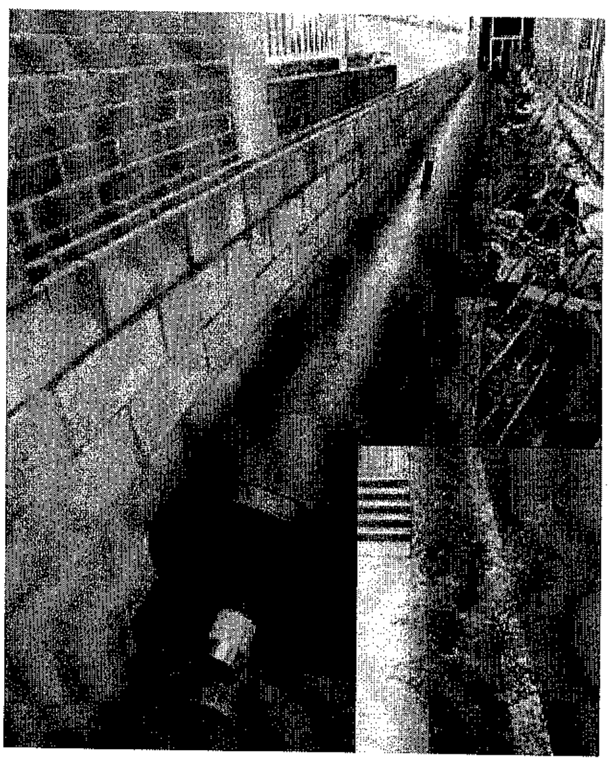
After Federated Department Stores closed the 750,000 square foot retail store in 2002, it donated the building to the Columbus Downtown Development Corporation. The building renovation completed in 2007 achieved LEED® Gold certification and the building's largest tenant is Ohio EPA. The renovated building includes a rainwater collection and reuse system. The system makes use of an existing 40,000 gallon tank on the building's roof and a new 50,000 gallon tank installed in the basement. The collected rainwater is used for toilet flushing, irrigation, and HVAC makeup. A biodegradable blue dye is added to the water used for toilet flushing to visually identify it as non-potable water. The system reduces potable water use in the building by several million gallons a year.[31, 32]

Stephen Epler Hall, Portland State University

PSU's 62,500 square foot mixed-use student housing facility (classrooms and academic office space are located on the first floor) was completed in 2003 and is LEED® Silver Certified. The stormwater management system was designed to be engaging to the public; rain from the roofs of Epler Hall and neighboring King Albert Hall is diverted to several river rock "splash boxes" in the public plaza.[33] The water then travels through channels in the plaza's brick pavers to planter boxes where it infiltrates and is filtered before being collected in an underground cistern. UV light is used to treat the water prior to its reuse for toilet flushing in the first floor restroom and irrigation. Placards located in the water closets indicate that the non-potable toilet flushing water is not for consumption. The stormwater collection and reuse system conserves approximately 110,000 gallons of potable water annually, providing a savings of $1,000 each year.[34, 35]

Natural Resources Defense Council's Robert Redford Building, Santa Monica

NRDC's renovation of a 1920s-era structure in downtown Santa Monica achieved LEED® New Construction, Version 2 Platinum certification. The innovative water systems in the 15,000 square foot building are a key component of the project's sustainability. The plumbing system delivers potable water only to locations where drinking water is needed, such as faucets and showers. Water from the showers and sinks is collected in graywater collection tanks and treated on-site. The treated graywater is reused for toilet flushing and landscaping. Rainwater from the building is collected in outdoor cisterns, which were installed beneath planters adjacent to the building. The collected rainwater is filtered prior to being added to the graywater collection tank as part of the water reuse system. The graywater/rainwater reuse system and high-efficiency features such as duel-flush toilets, waterless urinals, and drought-tolerant plants reduce potable water demand by 60%. Each waterless urinal, for instance, saves 40,000 gallons of water each year.[36]



Rainwater cistern at NRDC's Santa Monica Office (inset photo after planter planting). *Photo: NRDC.*

The City's plumbing code complicated the installation of many of the building's water features. The plumbing code prohibited waterless toilets or urinals, requiring a resolution that allowed the waterless urinals to be installed with water supply stubbed out behind the wall if needed for future use. The City is now seeking a change to City Code to allow for waterless urinals to be installed without an available water supply. Similarly, California's graywater ordinance did not contain a provision for rainwater collection; an agreement was negotiated with the County Health Department after which the City's Building and Safety Division agreed to sign off on the plans.[37, 38]

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Answers to Practice Questions

Chapter 1

1. Alternative water sources should be considered to reduce potable water use, be sustainable, prepare for reductions in available water, etc.
2. The ultimate goal of using an alternative source is autonomy over the water source.
3. economics, politics, regulation, owner's preference

Chapter 2

1. c
2. suspended solids, dissolved solids, chlorides, iron, heavy metals, solvents
3. surface water, gray water, storm water, rainwater, cooling water condensate, effluent water
4. pros: large quantity, good economics
   cons: highly regulated, variable quality

Chapter 3

1. submersibles, turbines
2. recovery rate
3. c
4. a
5. b
6. 10 gpm
7. foundation under drains, infiltrated pond water

Chapter 4

1. streams, ponds, rivers, lakes
2. D
3. C
4. A
5. 651,658 gallons
6. permitting, regulation, access, quality
7. considered potable, bank disturbance, navigation, dewatering, withdrawal limits

Chapter 5

1. 1.71 inches
2. 19,347 gallons
3. 23,277 square feet
4. the potential amount of water collected
5. because the tank could float
6. risk and economics

Chapter 6

1. gray water and black water
2. toilet, kitchen sink
3. determine what the local regulations are

Chapter 7

1. smart controllers, soil moisture sensors, storage tanks
2. Smart controllers are climate-based as opposed to time-based scheduling.
3. Yes — the more the watering is delayed the more storage may be needed.

Chapter 8

1. storm water, rainwater, ground water, gray water