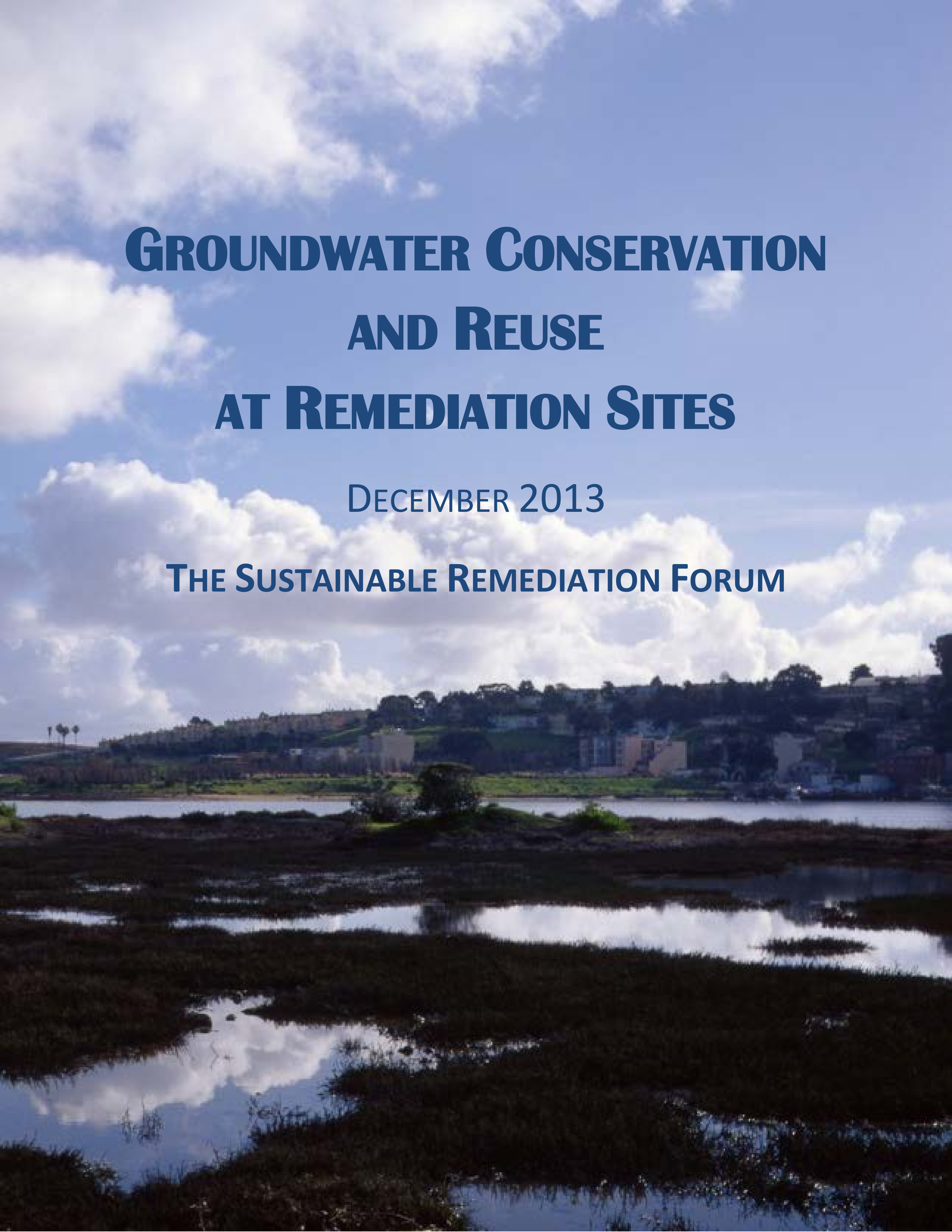
Groundwater Conservation and Reuse at Remediation Sites

December 2013

The Sustainable Remediation Forum



DISCLAIMER

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FOREWORD

The Sustainable Remediation Forum (SURF) promotes site assessment and remediation that protects human health and the environment while maximizing environmental, social, and economic benefits throughout the project life cycle. SURF members advance the organization's mission by making presentations at conferences and meetings, sharing knowledge and the current state of the practice at regularly scheduled SURF meetings, publishing sustainable remediation concepts and case studies in technical journals, and "walking the talk" during their daily activities.

It is the intent of this document to encourage efforts at water conservation and reuse by providing information and examples to all interested parties involved in cleanups. While it may seem intuitive to many of us in the business of cleanups that groundwater conservation and reuse at remediation sites should be considered more frequently and evaluated more thoroughly than it has been to date, the concept may still be a significant paradigm shift for many others. To encourage a paradigm shift and recognize current efforts, we offer this document.

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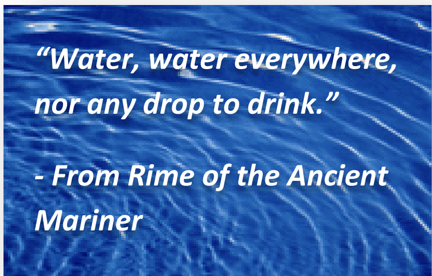
THE IMPORTANCE OF WATER

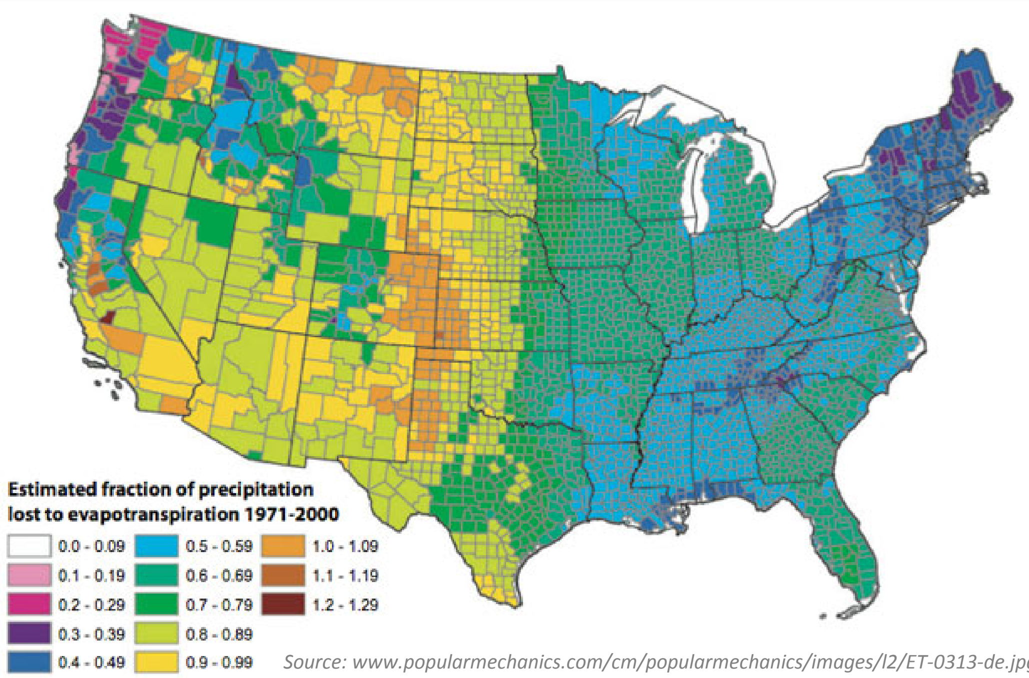
Perhaps you've heard the saying, "Water is Life." The abundance (or scarcity) of water has determined the pattern and extent of where civilization has developed and what it has become. Water is a source of recreation and relaxation – we seek it out whether it is a gently flowing stream or a water fountain in a park. Because of its importance, the theme of water is central in literature, culture, and art.



Despite the importance of water, we rarely think about how much (or how little) water is available for our everyday use. Generally, our collective societal conscience about water vacillates from feeling threatened during times of excess (flooding) to being concerned about our livelihoods during shortages (droughts). Unless there is an extreme condition of too much or too little we too often seem to take a safe and adequate supply of water for granted.

Water balance maps, like the one of the continental U.S. presented in Figure 1, show the relative availability of water. This map clearly illustrates the significant differences between precipitation and evapotranspiration patterns in the U.S. These patterns correlate with the relative abundance of surface water in the Eastern U.S. compared to the Western U.S. In locations like the Western U.S., our reliance on groundwater for public and other uses increases. The factors contributing to the pattern seen in Figure 1 explain why water "costs" more in some regions than in others. For example, the Western U.S. generally is described as very different from the Eastern U.S., largely due to differences in the abundance of water.

FIGURE 1
Water Balance in the Continental United States



Source: www.popularmechanics.com/cm/popularmechanics/images/l2/ET-0313-de.jpg

As the global population and the demand for water continue to increase, the challenge of supplying potable water becomes more prominent, requiring us to manage this natural resource in a sustainable manner. Figure 2 emphasizes this point by illustrating the water available in the world relative to the size of the earth. All of the fresh water is shown as the small dot in Figure 2.

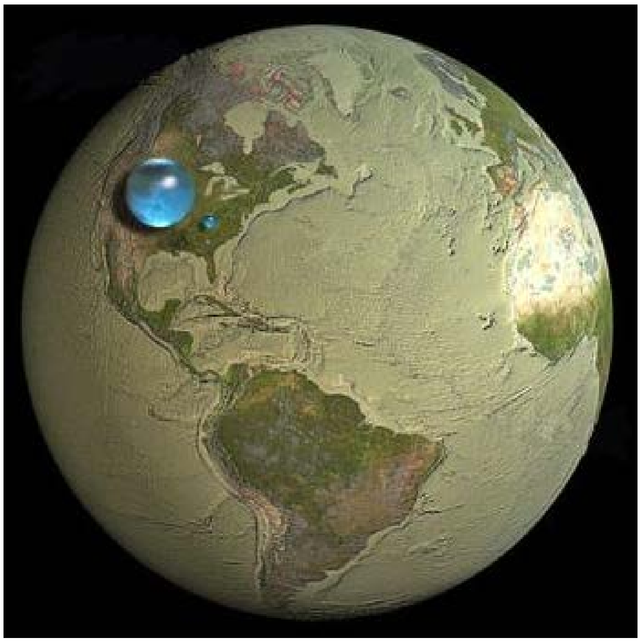


FIGURE 2
Water on Earth

The water available in the world is shown as a large droplet covering the Midwestern portion of the U.S. All of the fresh water of the world is illustrated as a much smaller droplet about the size of one state; groundwater is only a portion of this small droplet.

Source: USGS, ga.water.usgs.gov/edu/2010/gallery/global-water-volume.html

Water stewardship (or water sustainability) can be broadly defined as *"the responsible use, planning, and protection of water that is socially equitable, environmentally sustainable, and economically beneficial and that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend upon it"* (Gleick, 1996; Alliance for Water Stewardship, 2013). The integration of water stewardship into remediation projects through water conservation and reuse acknowledges the importance of water in our lives and our world.

GROUNDWATER CONSERVATION AND REUSE AT REMEDIATION SITES

Because water is important in so many ways, it is equally important to use it wisely. In the context of remediation projects, "wisely" translates into the conservation and reuse of groundwater. According to a recent report by the National Academy of Sciences, approximately 355 million gallons per day of reclaimed water is allocated to planned potable reuse projects in the U.S. (National Academy of Sciences, 2012). Although this amount accounts for only about 0.1% of the municipal wastewater undergoing treatment, the water being reused can (in some areas) account for the majority of an area's drinking water supply. These estimates reveal the significant opportunities for and the advantages of reusing potable and nonpotable water in the U.S.

To capitalize on these opportunities, groundwater conservation and reuse can be integrated into remediation projects. Remediation approaches for cleaning up contaminated groundwater can be classified into the following two broad categories: in-situ remedies (which may result in groundwater conservation) and ex-situ remedies (which may result in groundwater reuse or disposal). By definition, in-situ remedies treat groundwater contamination in place, thereby leaving the groundwater in the aquifer. Ex-situ remedies extract contaminated groundwater from the aquifer and treat it aboveground.

Historically, the most common approach to cleaning up groundwater contamination has involved ex-situ pump-and-treat systems. Though reuse options for treated groundwater can be considered and evaluated, these systems often dispose of treated groundwater in the sanitary sewer system [U.S. Environmental Protection Agency (USEPA), 2007]. At sites where these systems operate, treated groundwater can be reused for beneficial purposes such as agriculture, irrigation, or wetlands ecosystems. In addition, treated groundwater can be reinjected into the aquifer. This reinjection allows the remedy to become a net-zero water use operation (i.e., no water is lost). In addition, the treated groundwater can become part of an in-situ remedy that enhances flushing and accelerates cleanup.

Sustainable remediation, of which groundwater conservation and reuse is a significant part, promotes a growing awareness of the value of water resources. In Figure 2, groundwater represents only a portion of the small droplet. Groundwater contamination decreases the size of this small droplet even further because it prevents the use of groundwater for drinking water. Studies and real-life examples show that groundwater can be treated and reused safely, while providing benefits such as mitigating water scarcity concerns and providing lower cost water sources for alternative uses (Groundwater Replenishment System [GWRS], 2004). By integrating groundwater conservation and reuse concepts into remediation projects, water availability will increase and water will become a more sustainable resource.

TABLE 1
Documents and Tools to Evaluate the Triple Bottom Line

The following list provides examples of the documents that were developed to help remediation practitioners evaluate the environmental, economic, and social impacts of remediation:

- In 2008, the USEPA developed the Superfund Green Remediation Strategy to reduce greenhouse gas emissions and other negative environmental impacts that may occur during remediation. The strategy recommends the development of white papers focusing on the incorporation of sustainable remediation practices under existing laws and regulations (USEPA, 2010).
- The Decision Framework for Incorporation of Green and Sustainable Practices into Environmental Remediation Projects was issued by the U.S. Army Corps of Engineers in 2010.
- The following three documents were issued by SURF in 2011: Framework for Integrating Sustainability into Remediation Projects (Holland et al., 2011); Metrics for Integrating Sustainability Evaluations into Remediation Projects (Butler et al., 2011); and Guidance for Performing Footprint Analyses and Life-Cycle Assessments for the Remediation Industry (Favara et al., 2011).
- In 2011, the Interstate Technology & Regulatory Council (ITRC) issued the Technical/Regulatory Guidance – Green and Sustainable Remediation: A Practical Framework (ITRC, 2011).

CURRENT STATUS AND FRAMEWORK

Because water is vital to life itself, it is a key component of sustainability. Recently, sustainability has become a part of the mainstream interests and activities of virtually every sector of modern society. Sustainability is formally studied, evaluated, and discussed as being composed of the following three elements: environmental, economic, and social. These elements are readily apparent in the many benefits associated with a reliable and abundant supply of water. It is this obvious reliance and need for water that has led SURF to explore groundwater conservation and reuse in remediation projects, emphasize potential opportunities for application, and highlight best practices.

Current Status

Over the last decade, documents addressing sustainable remediation have been published, and tools and approaches for assessing sustainability aspects in remediation projects have been developed (see Table 1). While it requires some effort to quantitatively evaluate sustainability parameters throughout a project's life cycle, these documents and tools have prompted remediation professionals to consider the conservation and reuse of groundwater as a sustainability parameter in remediation projects.

When discussing the details of applying groundwater conservation and reuse principles to cleanup projects, remediation practitioners often point to the long-standing history of reusing treated wastewater in the municipal wastewater industry. For example, facilities in Orange County and San Diego (both in California) have extensive networks of piping and facilities that allow treated wastewater to be reused for irrigation and other nonpotable uses. Furthermore, these facilities use treated wastewater to recharge aquifers and replenish the drinking water supply.

In 2004, total reclaimed water reuse in the U.S. was estimated as 1,690 million gallons per day. Reclaimed wastewater primarily is being reused for agricultural and landscape irrigation purposes, as well as industry purposes (e.g., as cooling

TABLE 1 (cont'd)

•In 2012, the USEPA issued the document Methodology for Understanding and Reducing a Project's Environmental Footprint (USEPA, 2012).

•Most recently, in 2013, ASTM published the Standard Guide for Integrating Sustainable Objectives into Cleanup (ASTM, 2013).

The following list provides examples of the tools that were developed to evaluate the environmental, social, and economic impacts of remediation practices:

•Environmental footprint analyses can be conducted using the Air Force Center for Engineering and the Environment (AFCEE) Sustainable Remediation Tool (SRT), the Naval Facilities Engineering Command (NAVFAC) SiteWise™ program, and the USEPA's Spreadsheet Environmental Footprint Analysis (USEPA, 2012). Remediation practitioners can use these tools to help them evaluate the sustainability metrics associated with greenhouse gas emissions, carbon footprints, energy use, and water use.

•The Institute of Sustainable Infrastructure developed the Envision™ tool and rating system to evaluate the community (i.e., social), environmental, and economic benefits of infrastructure projects, which includes water treatment and distributions systems.

•Previously developed life-cycle assessment tools and environmental impact assessment tools can also be used to assist remediation practitioners in assessing the sustainability of remediation practices.

and process water) (Wastewater Engineering, 2003). Estimates of reclaimed water reuse in 2012 are considerably higher, ranging from about 2,250 to 2,500 million gallons per day and representing about 7% to 8% of the 32 billion gallons of municipal effluent produced every day (USEPA, 2012). Other nonpotable, reclaimed water uses include fire protection, street cleaning, groundwater recharge, dust control, impoundments, seawater intrusion barriers, and environmental restoration activities (e.g., stream augmentation, habitat restoration, engineered wetlands) (National Academy of Sciences, 2012).

Using these documents, tools, and the municipal wastewater industry's reuse of treated effluents as a guide, remediation practitioners are applying water stewardship concepts into the design, implementation, and maintenance of remediation systems for contaminated groundwater.

Current U.S. Framework

In the U.S., state and federal programs (e.g., Superfund) were established in large part in reaction to unexpected, wide-ranging groundwater contamination. This reaction led to the protection of groundwater quality that is inherent in the regulations governing groundwater remediation today. Current water quality standards require that treated groundwater quality be suitable for the intended reuse application. Although these regulations protect groundwater quality, they do not emphasize the beneficial reuse of the water that all too often is lost as a result of remediation activities.

No federal water reuse regulations exist in the U.S. to date. Instead, water reuse regulation primarily is under the jurisdiction of the states. The regulations developed by states vary, and some states have yet to develop water reuse guidelines or regulations. In September 2012, the USEPA published *2012 Guidelines for Water Reuse*. These guidelines update those published in 2004 and are aimed to support regulations and guidelines developed by states. According to the USEPA, 30 states and one territory have adopted water reuse regulations and 15 states have guidelines or design standards that govern reuse (USEPA, 2012).

CHALLENGES

At first glance, integrating groundwater conservation and reuse in remediation projects appears to be an obvious choice. But the cleanup of groundwater contamination in virtually any aquifer system is complex. These complexities can result in long remediation times and energy-intensive remediation efforts that, at some sites, have not resulted in the level of cleanup required. Challenges arise when the complexities of a remediation project are combined with the barriers associated with groundwater conservation and reuse. In practice, challenges such as water quality impacts, water balance and reliability, economics, public perception, and actual and perceived liabilities can hinder the successful conservation and reuse of groundwater during the design, implementation, and maintenance of remediation projects.

Water Quality Impacts

The extent of groundwater contamination depends on specific hydrological parameters and may result in large or small and mobile or stagnant plumes. Undetected heterogeneities in the subsurface can impede remediation, as evidenced in variations in the quality of water between two adjacent monitoring wells. Regardless of these complexities, for groundwater reuse, the quality of treated groundwater must be suitable for the intended reuse application. Secondary and indirect water quality impacts present challenges to integrating groundwater reuse into remediation.

> ***Let there be work, bread, water and salt for all.***
>
> ***- Nelson Mandela***

- ***Secondary Water Quality Impacts***
  The presence of treatment system by-products or differences in water chemistry (e.g., pH, redox conditions, temperature) can lead to secondary water quality impacts. As one example, the disinfection by-product N-nitrosodimethylamine is often present in tertiary treated wastewater, and questions about its fate and transport through the vadose zone and attenuation in groundwater aquifers can be a significant uncertainty for large water reuse projects, including Orange County's GWRS. As another example, iron and manganese precipitates can form if the redox conditions of the injected groundwater do not match the redox conditions of the aquifer. The discharge of sufficiently large volumes of treated groundwater to surface water can change the receiving water's temperature, turbidity, or concentrations of dissolved metals, which can impact surface water ecosystems.
- ***Indirect Water Quality Impacts***
  Indirect water quality impacts can also occur. For example, large-scale groundwater replenishment projects may have regional water quality implications if rising water tables contact residual contaminants that are present in the deep vadose zone. Similarly, the injection of treated groundwater can spread contaminants that are already in the aquifer. As one answer, the concept of a "treatment zone" surrounding the injection wells and delineated by downgradient compliance wells has been approved by several regulatory agencies.

Water Balance and Reliability

At large contaminated sites located in areas with a growing population and a heavy reliance on groundwater, the quantity of groundwater extracted from the groundwater aquifer can significantly affect the aquifer water balance and, in turn, the reliability of the water supply. It is common for groundwater remediation systems to operate for extended periods of time – typically decades – and for there to be prolonged periods of reduced flow, periodic maintenance shutdowns, or the eventual reduction in water extraction rates when the plume begins to decrease in size. While these disruptions may be tolerable and even inconsequential for the eventual cleanup, they can cause a significant water reliability challenge.

When groundwater is being reused as part of a groundwater extraction and treatment system, the groundwater reuse plan should provide not only a safe average rate of delivery, but also considerations for the range of flows expected, potential interruptions, and alternate water supplies. In addition, a contingency plan should be developed for when the system or process reusing the treated groundwater is not operating.

> ***Water is going to be the oil of the 21st century.***
>
> ***- Bill Cooper***

These challenges can be overcome by recognizing the end user as both a stakeholder in the cleanup and a collaborator in the design and implementation of the reuse project. For example, groundwater in the San Fernando Valley in California is regionally contaminated and could impact water reliability. At large sites like this one, remediation professionals must coordinate with local municipalities and adhere to urban water management and groundwater basin plans (e.g., some cities prohibit the installation of new water supply wells within city limits), perform monitoring, and manage flow options and contingencies so that the amount of water can be anticipated and potential impacts avoided.

Economics

The challenges discussed above affect the economics of groundwater conservation and reuse. Although the impact of contaminants can require additional treatment of the groundwater prior to reuse, these additional treatment costs may be less than the shipping costs associated with transporting fresh water onto the site or wastewater off of the site. These challenges add to the complexity and cost of reusing water from a cleanup and need to be clearly understood by all parties involved — particularly the eventual end user.

In addition, the economics of water conservation and reuse depend strongly on local policies, regulations, and water rights structures (e.g., Heberger, 2011). In areas with a growing population and a heavy reliance on groundwater, local incentives for water conservation and water reuse activities may exist. In other areas, the complexity and uncertainty of water economics, water rights, and banking or credit structures can be a barrier when implementing groundwater conservation and reuse.

Water Reuse in the News

In a February 9, 2012 article, the New York Times discussed the public sentiments expressed as San Diego, California considered reusing treated wastewater as a part of their drinking water supply. Referred to as "the yuck factor," there is nonetheless a successful pilot operation ongoing. This certainly offers an opportunity for learning about how to address similar objections that might arise from proposed conservation and re-use options at cleanup sites, notably wellhead treatment (Barringer, 2012).

Public Perception

Public perception of water conservation and reuse is typically favorable. However, regional differences in public awareness and perception of the value of water exist. Based on a survey, public attitudes about water indicate that people assign a value to water that is consistent with its lowest use (e.g., hosing off the driveway or sidewalk) (American Water Works Association Research Foundation, 2008). Research has repeatedly shown that public attitudes and perceptions often reflect the level of trust and general reputation of a water utility or organization proposing the water reuse project (American Water Works Association Research Foundation, 2008). Several projects emphasize the role of trust and provide ways to build trust to improve public perception of a project (Water Environment Research Foundation, 2009).

The public concern of further risk of exposure when reusing treated water can be overcome with rigorous monitoring and educational outreach. Much of our drinking water in many areas is recycled to some extent. River water used as a drinking water source in one downstream city already has been used and treated by upstream cities. The potential for an unknown contamination to emerge later is likely no greater with reused treated water than with the water we drink daily (Chu, 2011).

Actual and Perceived Liabilities

When reuse options are considered for a remediation project, actual and perceived liabilities pose challenges to reusing treated groundwater. Actual liabilities relate to the additional health and environmental risks associated with reuse. The treated groundwater reuse scenario must consider if and how reuse may expose the public to residual chemicals still in the water and must determine the acceptable concentrations of these chemicals. Depending on the results of this evaluation, additional water treatment requirements may be needed.

While the actual liability related to compound exposure can be quantified and assessed, perceived liabilities do not relate directly to any exposure. Generally, perceived liabilities are associated with the following:

- New contaminants can emerge and be identified in the treated groundwater.
- Cleanup level criteria can decrease.
- The toxicity of a compound can be reevaluated and modified.

Water is the driving force of all nature.

- Leonardo da Vinci

Discussions associated with the "fear of the unknown" weigh prominently when addressing these perceived liabilities, and such perceived liabilities can outweigh any benefit that reuse can provide.

THE GOLD STANDARD: THE SUCCESS OF THE ORANGE COUNTY SYSTEM

The Orange County Water District's (OCWD's) Groundwater Replenishment System (GWRS) in Southern California has become the gold standard for recycled groundwater projects. In this California county, the growing population, arid climate, and increasing limitations on the water that can be obtained from outside of the region have inspired innovative solutions from the OCWD water managers. As such, many valuable guidance principles for contaminated water purification and reuse (wastewater from sewage treatment plants in this case) can be gleaned from the successful implementation of the GWRS in Orange County.

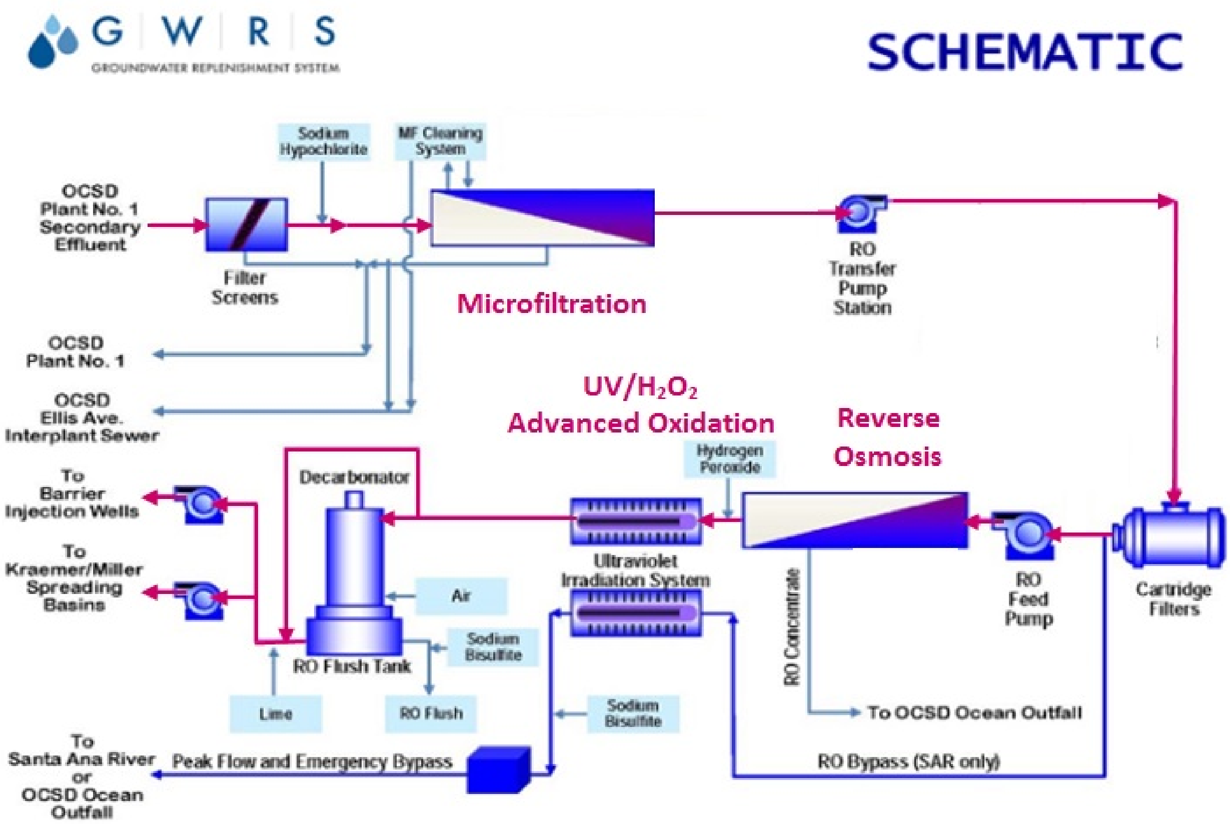


FIGURE 3
Key Process Flow Components of Groundwater Replenishment System (OCWD, 2012a)

In 2008, the GWRS was completed as an expanded replacement of the pioneering Water Factory 21 facility. Figure 3 presents a flow schematic of the process. This facility was the first project in the world to perform advanced treatment of wastewater and inject it into coastal drinking water aquifers beginning in 1976 (see Figure 4). The injection of fresh water into the aquifer using wells creates a protective hydraulic barrier to seawater intrusion, preventing water quality degradation of susceptible coastal drinking water wells.

The current GWRS treats 70 million gallons per day of secondary-treated wastewater effluent from the Orange County Sanitary District through a three-step purification process: microfiltration, reverse osmosis, and advanced oxidation UV/H_2O_2 treatment (see Figure 3). This treatment is effective at removing trace organics and heavy metals and achieves water quality near that of distilled water (OCWD, 2012a). An average of 30 million gallons per day is injected into coastal aquifers, while the remaining 40 million gallons per day are conveyed 13 miles to percolation ponds in the inland cities of Anaheim and Orange. In the percolation ponds, the water infiltrates through gravel and sand beds to replenish other areas of the groundwater basin which provides a sustainable, indirect potable water source (OCWD, 2012a). The GWRS produces sufficient potable water to supply 600,000 Orange County residents while preserving and improving the quality of the County's primary source of potable water—the coastal groundwater basin.

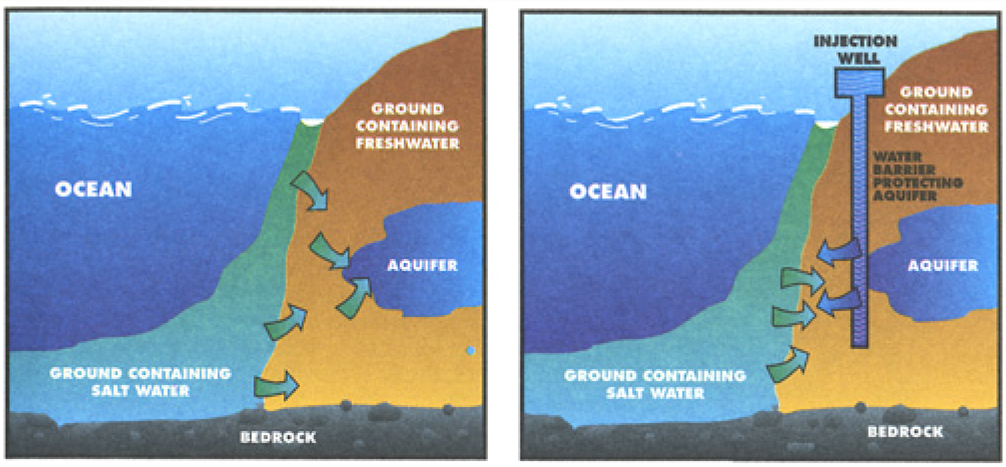


FIGURE 4
Seawater Intrusion Barrier with Treated Wastewater Injections

Source:
West Basin Municipal District, 2013

Overcoming Challenges

The risk of unknown contaminants when reusing treated wastewater is a concern for water treatment system managers and community stakeholders. Increased contaminant loads on water systems and improved analytical techniques have contributed to the discovery of new water pollutants, regardless of the water source. The GWRS and its predecessor, Water Factory 21, are great examples of using rigorous site characterization, ongoing water quality monitoring, exemplary treatment technologies, and effective public outreach to reduce the fear associated with these poorly characterized, "emerging" contaminants (Mohr et al., 2010).

In 2000 and 2001, the organic pollutants N-nitrosodimethylamine and 1,4-dioxane were detected in influent and effluent of Water Factory 21. Although not yet federally regulated, both of these emerging contaminants are considered potential carcinogens. Therefore, the injection of treated wastewater was halted as a precautionary measure until an acceptable solution was determined. Within a year, an advanced oxidation UV/H_2O_2 system was added to the treatment process to successfully disinfect and degrade trace organics that may have made it past the traditional wastewater treatment and reverse osmosis membrane. This additional treatment successfully degraded N-nitrosodimethylamine and 1,4-dioxane to concentrations below proposed safety guidelines, and regular operations continued (Mohr et al., 2010).

TABLE 2 – Lessons Learned from Groundwater Reuse Projects

Challenges	Solution Strategies and Precautionary Actions
Potential for Emerging Contaminants in Treated Groundwater	• Be proactive in obtaining comprehensive site characterization, contaminant source characterization, and proper risk assessments. • Survey the literature for similar contamination and/or reuse experiences. • Design flexibility into the system or install additional treatment technologies or safeguards that remove emerging contaminants of concern. • Maintain rigorous and ongoing monitoring of regulated and nonregulated contaminants of potential concern before releasing treated groundwater into the environment. • Control upstream source(s) if ongoing contamination is expected.
Public Objections and Misconceptions	• Be trustworthy in your business practices and earn a reputation as a "community partner." • Be transparent and cooperative with all stakeholders in the decision-making process (e.g., water quality reports of recycled water end product, oversight by independent advisory board or government agency). • Moderate the fear of reused groundwater, eliminate misconceptions, and promote the benefits of reuse as it relates to proposed project (e.g., conservation, sustainability, water quality exceeding all state and federal water standards). • Leverage previous positive experiences with the technology or process. • Create positive and informational tools for website or brochures (e.g., a webcam of site progress or advanced technology in action, informational video emphasizing benefits and safety).
Economic Costs	• Compare the potentially favorable energy and other life-cycle costs of producing recycled water with alternative water sources such as imported water. • Pursue alliances with potential cost-sharing partners that share common water quality/conservation interests (e.g., sanitation districts, water retail agencies) or those that have complementary resources (e.g., analytical laboratories, research universities) and build consensus on how all can share in the benefits and costs of groundwater reuse. • Include social and environmental costs and benefits in long-term cost-benefit analyses. • Take advantage of government grants and tax incentives that reward innovative and/or sustainable practices (e.g., SERDP and ESTCP, 2012; National Groundwater Association, 2012).

Notes:
SERDP = Strategic Environmental Research and Development Program
ESTCP = Environmental Security Technology Certification Program

The OCWD credits extensive public outreach as essential to the project's success in regard to the efficiency and safety of its GWRS (OCWD, 2012b). For example, the GWRS website includes informational videos describing the safety and efficiency of reverse osmosis and the UV/H_2O_2 oxidation processes and features an electronic ticker that counts off the running total of gallons of recycled water produced to date. A summary of lessons learned for groundwater reuse projects are provided in Table 2.

Successes in Sustainability

The GWRS in Orange County continues to be a success story for treating and reusing contaminated water in a cost-effective way. It provides a local additional source of 70 million gallons per day of reliable, high quality, potable water; protects the groundwater basin from seawater intrusion; and reduces the amount of wastewater being discharged into the Pacific Ocean — all outcomes that are widely supported by the local community. Scientific studies performed in the early 2000s concluded that the reused wastewater, after purification treatment, would actually "improve the groundwater basin's overall quality" (OCWD, 2004). Furthermore, a significant reduction in greenhouse gas emissions and energy costs are achieved because this indirect potable water supply comes at less than half of the energy currently required to import water from Northern California and one third the cost to desalinate water (OCWD, 2012a).

Orange County faced significant challenges due to water scarcity and water quality. The development and implementation of the GWRS demonstrates that challenges can be overcome when approached systematically and in a precautionary and transparent manner. Remediation practitioners can take a similar proactive and holistic approach at remediation sites to conserve water, preserve valuable ecosystem resources for neighboring communities, and deliver a cost-effective and community-approved solution — all while protecting human health and the environment.

Every gallon of water reused is one gallon less of fresh water that is needed.

TABLE 3
Using the Triple Bottom Line Approach to Evaluate Potential Groundwater Reuse

Environmental
Evaluating environmental impacts of treated groundwater reuse can be achieved using sustainability tools such as SiteWise™, the Green Remediation Evaluation Matrix (GREM), SRT, and the USEPA's Spreadsheet Environmental Footprint Analysis. These tools can be used to evaluate the difference, from an environmental standpoint, between disposing of and reusing treated groundwater. The types of outputs that can lead to a robust evaluation of the environmental effects of disposal vs. reuse include the following:

- Energy and materials consumption
- Change in resource service
- Greenhouse gas emissions
- Ecological system stress

Economic
Evaluating the economic aspects of treated groundwater reuse considers the cost difference between disposal and reuse of the treated groundwater. Considerations that can be used to complete this evaluation include the following:

- Cost savings to the end user of the treated water to incorporate recycled water into an existing process
- Cost to implement a discharge permit to a river or stream (e.g., sampling, inspections)
- Added cost to maintain public storm sewer infrastructure due to added volume to the system
- Sanitary disposal fees to dispose of the water
- Incremental cost to sanitary facility for re-treating the already-treated water
- Cost to the end user of the recycled water if delivery is unpredictable

A VISION FOR THE FUTURE

Although questions and challenges associated with conserving and reusing groundwater from remediation projects continue to emerge, SURF offers the following vision to increase the sustainability of remediation by conserving and reusing water.

Valuation of Groundwater

Too often, the value of groundwater is equated to local utility prices that have not represented the true cost of water. Historically, local utility prices were developed based on the exploitation of the water resource and did not consider the intrinsic value of groundwater. When developing remedial action objectives and groundwater cleanup goals, the function and services provided by groundwater should be considered. Depending on the importance of groundwater in a particular area, regional factors such as geography, climate, local industry, and population drive the valuation of groundwater.

Groundwater serves a variety of functions and provides a number of important services to both the human population and ecosystem. One of the most important services of groundwater is as a provision for drinking water, agriculture, and livestock. Groundwater also serves as a storage mechanism for future groundwater needed during droughts, provides benefit to ecosystems and human recreation when it recharges surface water systems, prevents salt water intrusion, dilutes contaminants, and prevents land subsidence. It is also utilized in manufacturing processes, power production, and cooling systems. Each of these functions and services can be represented by a number of valuation methods. Some of these methods include market pricing, contingent valuation, benefits transfer, supply or cost function, and ecosystem services. Some of these valuation techniques are described in detail in USEPA, 1991; Braden and Kolstad, 1991; and Freeman, 1993.

TABLE 3 (cont'd)

Additionally, the indirect costs associated with integrating recycled water into existing processes can provide a holistic review of water use options. The avoided indirect costs derived from reusing treated water include the following:

- Energy required to transport potable water to existing processes
- Future cost increases (i.e., economic and social) due to potable water scarcity because of aquifer and surface water overuse.

Social
Evaluating the social aspects associated with treated groundwater reuse considers the social benefits or impacts of disposal vs. reusing treated groundwater locally or regionally. The evaluation includes assessing the following:

- Benefits or impacts to the local or regional communities resulting from implementing the water reuse options vs. continuing with business as usual
- Benefits of engaging stakeholders in the decision process
- Future cost increases (i.e., social and economic) due to potable water scarcity because of aquifer and surface water overuse
- Worker safety

Quantification Using the Triple Bottom Line Approach

Remediation professionals and others would like a more reliable analytical approach when estimating the sustainability benefits of reusing treated groundwater. Consideration and quantification of the three aspects of the triple bottom line (i.e., environmental, economic, social) remains a challenge. Presently, societal costs and other externalities are often not included in an impact assessment of site remediation (Favara et al., 2011; Lee et al., 2009). In addition, economic evaluations are limited to cost-benefit analysis and rarely take into consideration the socio-economic benefit of site remediation.

The following suggestions can help quantify the sustainability aspects of groundwater conservation and reuse:

•Evaluate the efficacy of repurposing and reusing treated groundwater using the triple bottom line approach (see Table 3).

•Use the guidance documents and tools listed in Table 1 to assist in developing and defining sustainability metrics and indicators as well as the triple bottom line objectives for site cleanup and groundwater reuse.

•When establishing indicators and objectives for remedial activities, focus not only on site-specific risks, but consider external social and economic impacts beyond identified environmental impacts in order to protect human health and the environment [Interstate Technology & Regulatory Council (ITRC), 2011].

•Develop groundwater remediation and reuse scenarios with stakeholders to develop project-level "anticipatory capacity" to react to and resolve uncertainties and unforeseen complexities in social, environmental, and engineered systems in combined remediation and reuse projects.

In the absence of quantification, a more common sense approach can be used. Remediation practitioners and other stakeholders can ask themselves if discarding treated groundwater – after the investment of significant resources to collect and treat that water – is environmentally, socially, and economically preferable to reusing it under any circumstance. It seems difficult to find a circumstance in which the discharge of treated water to a sewer or storm drain is preferable to reusing the water, particularly in light of the resources needed and expended for treatment. As discussed previously, extracting groundwater from an aquifer impacts the aquifer system, if only by diminishing water availability. Therefore, achieving the highest beneficial reuse of groundwater in a remediation project may deter from the economic and cost-effective benefits of the system. This challenge can be overcome through additional planning and clear communication about expectations amongst all stakeholders.

Selection of Groundwater Remedy

Groundwater remedies are often complex systems which require a multimodal approach to achieve desired goals. Table 4 provides a nonexhaustive list and overview of common groundwater remediation technologies and their resulting impact on groundwater conservation or reuse. In the table, remedies are classified into four categories: (1) minimal action, (2) passive in-situ remediation, (3) active in-situ remediation, and (4) active ex-situ remediation. Additionally, a high level review of advantages and disadvantages with respect to water reuse and/or conservation, remediation duration, relative costs, and environmental footprint are provided.

Reevaluation of Practices

The selection of a remedy is just one way that remediation practitioners can conserve water. Water use can be minimized during remediation by reevaluating design and operation and maintenance practices with an eye toward water conservation. For example, water conservation can be achieved by selecting the appropriate size of and placement for wells and pumps, optimizing the remediation process, using low-flow purging and passive sampling methods, and developing and identifying water management best practices.

> ***My books are like water; those of the great geniuses are wine. (Fortunately) everybody drinks water.***
> ***- Mark Twain***

TABLE 4 – Remediation, Water Conservation, and Reuse

Technology	Description	Advantages	Disadvantages	Commentary
MIMINAL ACTION				
Institutional controls	This type of remedy leaves groundwater with concentrations above performance criteria in place and place restrictions on access to the public.	Low capital cost and initial environmental footprint (long term monitoring may have high cost and environmental burdens); administrative controls are placed on a specific area that can be demonstrated is stable in order to reduce the potential for exposing receptors.	Groundwater is not remediated and cannot be used as a potable source without treatment; groundwater may inadvertently be accessed resulting in exposure to receptors; long term monitoring will be required to demonstrate contamination is not migrating.	Groundwater is left in place and is not remediated. Access to contaminated groundwater is restricted by modifications to the deed and completion of a due care plan.
PASSIVE IN-SITU REMEDIATION				
Natural attenuation	Natural subsurface biological systems are used without input of external energy sources to contain or degrade the contaminant to concentrations below regulatory thresholds prior to reaching a compliance point.	Energy is not expended to achieve remedial goals; groundwater is not further altered or extracted from the subsurface.	Contaminants are degraded very slowly; monitoring, institutional controls, and financial assurance is required to remain in place for many decades; often times the degree of natural degradation of contaminants can be complicated, thus presenting many significant technical challenges in demonstrating effectiveness; if used as a standalone strategy the regulatory and public perceptions are generally poor; typically used for groundwater with relatively low concentrations of contaminants.	Natural attenuation uses natural biological systems to reduce the concentration of contaminants in groundwater without addition of amendments or removal of groundwater. This results in a low environmental footprint and low initial capital. However, long term monitoring is typically required for decades. In recent years, natural attenuation has been considered a component of groundwater remedies, however not typically as a standalone technology if contaminant levels are high compared to remediation goals.

TABLE 4 – Remediation, Water Conservation, and Reuse

Technology	Description	Advantages	Disadvantages	Commentary
Permeable Reactive Barriers (PRB) 	Contaminated groundwater flows under natural hydraulic gradients through a reactive medium to reduce contaminant levels.	After installation minimal energy is expended; groundwater is not extracted from the subsurface; wall failure due to exhaustion of reactive material has not been observed.	Mixing of clean groundwater exiting the PRB with contaminated groundwater immediately downgradient still results in groundwater above remediation goals for many years after installation; potable water usage will likely not be realized in the near term; environmental footprint may be high depending on the source of reactive material; high cost; if the reactive material is consumed, the PRB will need to be replaced.	PRBs are typically used in order to passively treat groundwater in-situ. Use of this technology results in no net loss of groundwater; however the concentration of contaminants in groundwater immediately downgradient of the PRB may not see significant reductions in concentrations for many years.
ACTIVE IN-SITU REMEDIATION				
In-situ bioremediation 	Amendments (i.e. vegetable oils, oxygen) are added to the groundwater in order to stimulate natural biological systems to degrade contaminants in groundwater.	No net loss of groundwater resource; minimal energy expended to produce and inject amendments; using natural systems to degrade contaminants.	Groundwater cannot be used immediately as a potable source due to addition of amendments; biological population increases slowly over time sometimes resulting in long lead times between addition of amendment and significant reduction in contaminant; may not be an adequate technology to address downgradient contamination; monitoring, institutional controls, may be required to remain in place for many years or decades; adequate delivery of amendments to groundwater in low hydraulic conductivity zones may limit effectiveness.	Enhanced bioremediation can be a good source area remediation technique in conducive environments which results in no net loss of the groundwater resource. However, large downgradient plumes often cannot be treated using this technology, increase of biological activity to required levels may take a long time to achieve, and the groundwater cannot typically be used as a potable source in the near term.

TABLE 4 – Remediation, Water Conservation, and Reuse				
Technology	**Description**	**Advantages**	**Disadvantages**	**Commentary**
In-situ oxidation 	Chemical oxidants (i.e. permanganate, hydrogen peroxide) are added to the groundwater in order to oxidize contaminants in source.	No net loss of groundwater resource; minimal energy expended to inject amendments.	Treatment of downgradient plumes is likely not cost effective and will may not be a suitable standalone treatment strategy for the site; high energy requirements to produce the oxidant; rebound of contaminant concentrations often persist due to diffusion from soil into groundwater over time; groundwater cannot be used immediately as a potable source due to presence of residual oxidant in the treatment area; application of chemicals in the presence of NAPL may result in clogging and will affect the ability to adequately deliver the chemical.	Chemical oxidation can be a good source area remediation technique that results in no net loss of the groundwater resource. However, downgradient plumes often cannot be treated, rebound of contaminants in the source area may persist, and the groundwater cannot typically be used as a potable source in the near term.
In-situ thermal 	Groundwater temperatures are raised to the boiling point where volatile organic compounds are transferred to the vapor phase in the soil vadose zone. Soil vapor extraction is typically used remove vapor for above ground treatment and then discharged to the air.	Generally can minimal net loss of groundwater resource; groundwater within treatment zone achieves remedial goals in a short time period (relative to other technologies); technology can achieve groundwater remedial goals in the presence of very high concentrations.	Energy intensive; technology may not be cost effective if source area contains low concentrations of contaminants; may not be an adequate technology to address downgradient contamination;	Thermal remediation is typically used to treat high concentration source areas in a short period of time (as compared to other technologies). This technology is extremely energy intensive and requires significant infrastructure to implement; however, when viewed over the project life cycle, the short duration may result in a smaller environmental footprint than other technologies.

ACTIVE EX-SITU REMEDIATION				
Pump and treat	Primary purpose is to gain hydraulic control of migration of contaminated groundwater. This is accomplished through physical removal of groundwater, treatment, and then discharge.	Produced water can be repurposed for beneficial use (potable water, industrial makeup water, etc.).	High energy demand; produced water volumes may not be reliable enough to be adequately used for repurposed process; additional capital cost and O&M required to instrument, install and monitor supply water for repurpose; systems are typically in operation for decades.	Groundwater is physically extracted from the subsurface for the purposes of gaining hydraulic control of the local groundwater flow. Groundwater is transferred via piping to a treatment system in order to remove contaminants from the groundwater. Extracted groundwater may be repurposed; however, in most cases the least costly method of handling treated groundwater is to discharge to sanitary or storm sewers.
Well-head treatment	Water contaminated at supply well (for potable or industrial use) is treated at the point of generation for subsequent use.	Contaminated water is extracted for the purpose of beneficial use.	Public concerns as well as historical preferences have limited this approach as a remedy; is identical to pump-and-treat systems in most instances, but of a generally larger scale.	Well-head treatment is generally perceived as a 'last resort' by regulatory agencies; has perception issues with shifting responsibilities from responsible parties to public agencies; liability concerns over emerging contaminants and other issues are significant barriers.

Notes:

Footprints represent the simplified relative magnitude of environmental impacts of the technology. All projects and technology implementation practices are different and site-specific; this scale should be considered as a simple broad-spectrum representation. Low impact technologies are generally in-situ, passive, or technologies that mimic natural processes; Moderate impact technologies are generally active in-situ, materials-intensive, or operationally complex; High impact technologies are generally energy-intensive, have high maintenance requirements, or operate for long periods of time.

= low-impact technology

= moderate-impact technology

= high-impact technology

CASE STUDIES

A summary table of 14 water conservation and reuse case studies is provided in Table 5. Expanded descriptions of these case studies are provided in Appendix A. Most of the case studies highlighted in this document were completed many years ago, with little formal deliberation over sustainability parameters. These case studies demonstrate the reuse of both treated groundwater and treated municipal wastewater at various sized sites throughout the U.S. A high percentage of case studies included herein are located in the western U.S., particularly in California.

> ***We never know the worth of water till the well is dry.***
>
> ***- Thomas Fuller***

The following three case studies in Table 5 are highlighted here:

- San Francisco Bay Area survey of treated groundwater reuse (Case Study #1 in Table 5)
- Water reuse at the former Unidynamics Superfund Site (Case Study #3 in Table 5)
- Industrial reuse of treated Groundwater (Case Study #7 in Table 5)

Elements of the Orange County Water District GWRS (Case Study #12 in Table 5) were provided previously to demonstrate the success of a large-scale wastewater reuse system involving reinjection and new and emerging contaminants.

Collectively, these case studies indicate that water conservation and reuse is being applied at a wide variety of sites.

San Francisco Bay Area Survey of Treated Groundwater Reuse

In 2012, a two-year old survey was updated to identify those groundwater remediation sites regulated by the San Francisco Bay Regional Water Quality Control Board that are reusing treated groundwater. The San Francisco Bay Regional Water Quality Control Board includes the following counties: Alameda, Contra Costa, San Francisco, Santa Clara (north of Morgan Hill), San Mateo, Marin, Sonoma, Napa, and Solano. The survey included 56 sites with permitted discharges under the San Francisco Bay Regional Water Quality Control Board's General Permit for sites containing volatile organic compounds (VOCs).

> Water conservation and reuse in remediation projects is not just a North American concern. During the course of developing this document SURF was contacted by a European practitioner who is a member of SuRF-Italia about examples of water conservation and reuse in Italy.

Of the 49 operating facilities, updated survey results indicate that only six are currently reusing treated groundwater. The primary types of water reuse are reinjection as a future supply source, industrial use, and irrigation. Figure 5 provides additional information about the types and volumes of reuse for the six facilities. With only about 20% of the treated groundwater by volume being reused and over 1.3 billions of gallons per year of treated groundwater being discharged to creeks or the San Francisco Bay, a significant opportunity exists to increase treated groundwater reuse.

Updated survey results indicate that the primary barriers to reusing treated groundwater are the lack of infrastructure, incentives, and the identified reuse application, yet a preliminary comparison of water quality indicates that treated groundwater may be of higher quality than discharges from tertiary effluent from four water treatment plants[1]. With California's goal to reduce urban per capita water consumption 20% by 2020, the reuse of water from treatment plants should be targeted as a primary potable reuse area and blending treated groundwater with recycled water should be considered as a way to augment this supply source.

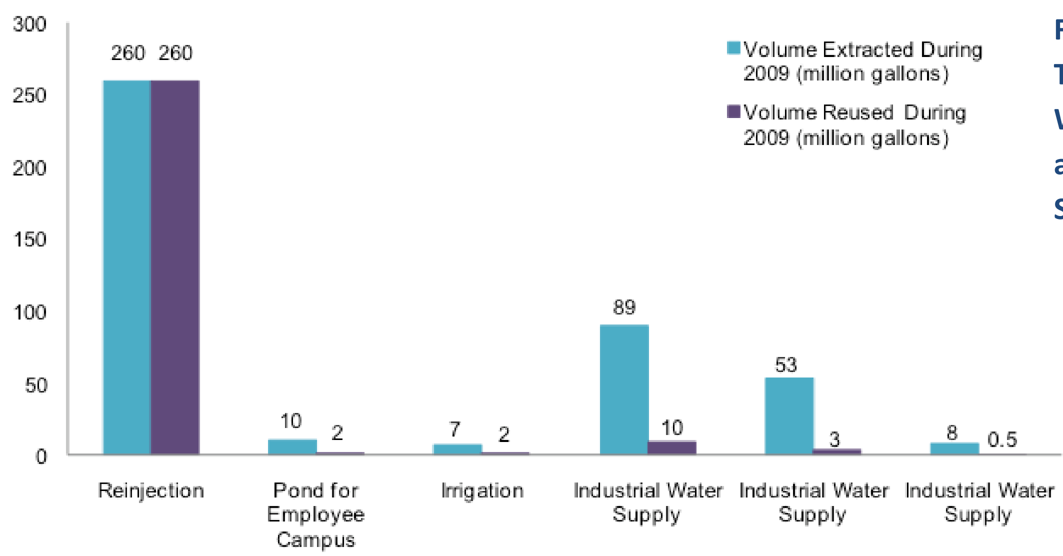


FIGURE 5
Types and Relative Water Reuse Volumes at Six Facilities in the San Francisco Bay Area

Source: Byler, 2010

Water Reuse at the Former Unidynamics Superfund Site

In the mid-1980s, the former Unidynamics Phoenix, Inc. facility in central Arizona was placed on the National Priority List because of soil and groundwater contamination. In 1994, remediation was initiated in the form of groundwater pump-and-treat systems with reinjection and a soil vapor extraction system with air emission controls. The site is located within the Sonoran Desert. Water pumped from the aquifer within this arid environment (average annual rainfall of approximately 8 inches) is a precious resource. To make sure that the

[1] Comparison based on total dissolved solids in effluent from South Bay Water Recycling and the cities of Palo Alto, Redwood City, and San Diego, California.

water extracted from the aquifer was beneficially reused, agreements were negotiated with local entities to allow for treated groundwater to be used as an irrigation source and also reinjected back into the aquifer. These agreements guaranteed that water extracted from the aquifer was reused, reaping economic, environmental and social benefits for the nearby area.

The considerations associated with Superfund requirements differ from other sites in that Superfund sites are exempt from many of the water rights laws and permitting requirements associated with groundwater pumping and distribution for irrigation use in Arizona. However, similar to other sites, the remedial actions must continue to progress, protect human health and the environment, and be reviewed and approved by the USEPA and other stakeholders.

Five groundwater pump-and-treat systems operate at the site and receive contaminated groundwater from 13 extraction wells. The aggregate flow from the extraction wells is approximately 2,800 gpm, of which approximately 1,600 gpm treated groundwater is returned back to the aquifer through a series of 12 injection wells. The remainder of the remediated groundwater (approximately 1,200 gpm) is used for dust control; irrigation of local agriculture, a golf course, and a local city park; and precooling of HVAC cooling water by a local school. For the latter, water is conveyed to a heat exchanger in a closed-loop system and eventually reinjected into the aquifer.

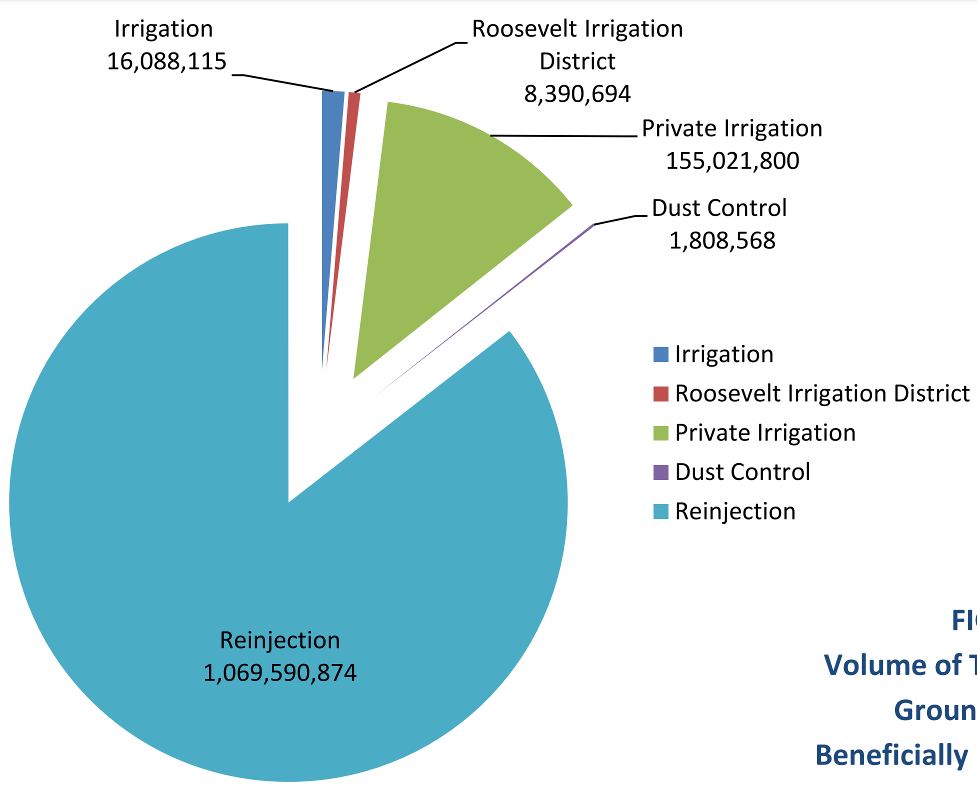


FIGURE 6
Volume of Treated Groundwater Beneficially Reused
(based on 2011 data)

The design and operation of these pump-and-treat systems provide the following economic, environmental, and social benefits:

- ***Economic***
  The treated precooling water provided by the site to the local school has allowed the school to reduce its heating and cooling costs by 40%.
- ***Environmental***
  As shown in Figure 6, 100% of water extracted for the remedial action is beneficially used, either through reinjection, irrigation, or dust control. Approximately 2.1 million gallons per year is used for cooling water for the local school and then reinjected into the aquifer.
- ***Social***
  Reinjecting over 1 billion gallons of treated groundwater into the aquifer minimizes the impact on the precious groundwater resource.

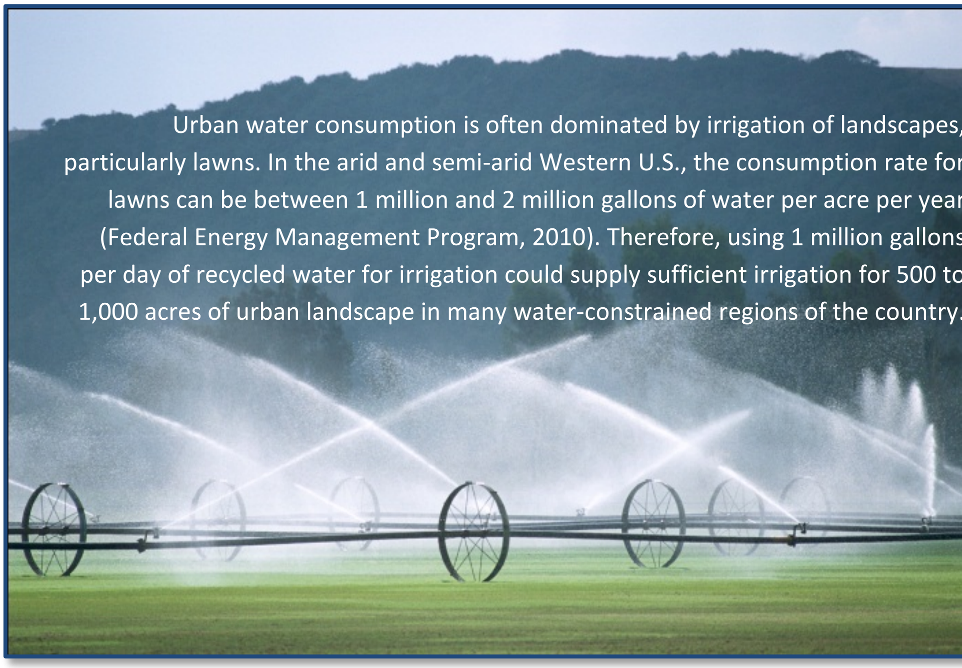
Industrial Reuse of Treated Groundwater at an Aerospace Facility

At an aerospace facility in Huntington Beach, California, site investigations identified VOCs in groundwater that required remediation. Through feasibility studies and focused pilot-scale testing of cleanup technologies, a groundwater pump-and-treat system was selected as the preferred remedial approach. Water conservation and reuse principles were integrated into the remedial approach, resulting in significant environmental, economic, and social benefits.

Two options were identified to integrate water conservation and reuse into the pump-and-treat system. The first option focused on optimizing the system during the design phase to minimize the amount of water extracted. The second option focused on reusing the treated groundwater, which involved evaluating the following considerations usually not considered in pump-and-treat systems.

- Facility operators were included as stakeholders in the project so that their input could be obtained early in the process.
- A water audit was conducted to determine how much of the treated groundwater could be reused, where it could be reused, and the time pattern of reuse.
- A contingency plan was developed for instances when operations are shut down or reduced.
- Potential VOC exposure both on- and off-site were assessed.

With the reuse option as a goal, considerations associated with regulatory requirements were evaluated and appropriate regulatory review and approval was obtained. Because the treated groundwater would be intermittently (rather than continuously) discharged to the sewer, industrial discharge permits were modified. The conservation aspects of the reuse plan were submitted to the water district, which supported it. The design of the nontraditional pump-and-treat system was submitted to the appropriate regulatory agency, which provided its review and approval.



In the system, "high concentration" groundwater and "low concentration" groundwater are extracted separately, conveyed through separate piping systems, and treated separately before reuse. Both activated carbon (low energy) and oxidation (high energy) treatment systems are employed to accomplish an overall lower energy usage. Treated groundwater is conveyed and used in nearby cooling towers. The reuse system includes robust controls and provides a back-up water supply to the cooling towers. When the towers are not operating, treated groundwater flows to the sanitary sewer system. In addition, treated groundwater can be sent to other areas for potential water reuse at the facility.

Through careful planning, the system is providing significant economic, environmental, and social benefits as described below.

- ***Economic***
  A portion of the capital investment was offset by regulatory incentive programs for water conservation. The predicted payoff for the capital investment is from three to five years due to cost savings in water purchases. In future years, overall operation costs are projected to be lower.
- ***Environmental***
  The reduced net demand for water is 80,400 gallons per day. Water which would have been needed is now available for other uses – both on- and off-site in the community. Greenhouse gas emissions associated with the treatment system were reduced by 110 metric tons per year due to the tailored matching of both high and low energy treatments to the appropriate groundwater streams.
- ***Social***
  The reuse of water provides the facility with an increased self-reliance on water resources, which, in turn, helps local regulatory agencies to meet their goals for reducing the demand of potable water.

TABLE 5 – Summary of Water Conservation and Treated Groundwater Reuse Case Studies

Case Study Number	Case Study Title	Contaminants of Concern	Regulatory Regime and/or Permitting	Summary
1	San Francisco Bay Area Survey of Treated Groundwater Reuse	VOCs	Regional Water Quality Control Board	An evaluation of treated groundwater reuse was performed in 2010 and updated in 2012. Sites that reused treated groundwater were identified, and specific sites were selected to be interviewed to determine commonalities or barriers to reuse. Results show that six of 49 operating groundwater treatment facilities reuse treated groundwater. Of the 49 operating facilities, total extracted groundwater volume is greater than 1.4 billion gallons per year, with about 20% reused for reinjection (one site), industrial supply (three sites), decorative pond (one site), and irrigation (one site) among others.
2	Treated Groundwater Reuse at United Technologies Corporation Former Missile Propulsion Testing Facility	VOCs; PCBs; TPH; Perchlorate; 1,4-Dioxane	Regional Water Quality Control Board	The site has been reusing treated groundwater since 1991 for irrigation and dust control. VOCs were detected in on-site creeks, providing a pathway for potential contaminant transport to a downstream reservoir. Water treated at the on-site groundwater treatment plant is routed directly to two on-site storage ponds to help manage water levels. To maintain 2 feet of freeboard space in the ponds, the treated groundwater is periodically sprayed on nearby landscaping and pastures without causing surface water runoff.
3	Water Reuse at the Former Unidynamics Superfund Site	VOCs	Superfund	This site, located in Central Arizona within the Sonoran Desert, achieves 100% reuse of treated groundwater. Five of the pump-and-treat systems operating at the site receive contaminated groundwater from 13 extraction wells. About 57% of remediated groundwater is returned back to the aquifer through a series of 12 injection wells. The remainder of remediated groundwater is used for dust control, cooling water, and irrigation of local agriculture and a golf course.
4	Treated Groundwater	VOCs	EPA, state environmental	This site contains a VOC-contaminated groundwater plume beneath commercial and residential properties. A pump-and-treat system

TABLE 5 – Summary of Water Conservation and Treated Groundwater Reuse Case Studies

Case Study Number	Case Study Title	Contaminants of Concern	Regulatory Regime and/or Permitting	Summary
	Reused as Drinking Water at Superfund Site in Nebraska		agency, state department of health	intercepts the plume and treats it using a packed column air stripper. Treated groundwater is reused as drinking water rather than discharging it solely to a storm sewer or conveying it to a wastewater treatment plant. In three years, nearly 800 million gallons of treated groundwater water has been provided as drinking water to the city.
5	Hydraulic Containment and Reinjection System for Treatment of Groundwater VOCs	VOCs, 1,4-Dioxane	EPA, land use restrictions and/or post-closure permit	At this site, a hydraulic containment and reinjection system is used to contain a groundwater VOC plume and protect drinking water. UV/H2O2 oxidation was used to degrade the 1,4-dioxane. In its first 18 months of operation, the UV/H_2O_2 oxidation system reduced 1,4-dioxane concentrations from 110 parts per billion (ppb) to below 1.0 ppb. The site achieves 100% reuse of treated groundwater through reinjection into the subsurface.
6	Glendale Water Treatment Facility: Remediated VOC Groundwater for Residential and Drinking Water Use	VOCs, Chromium	EPA, state department of health, local municipality	This facility remediates approximately 7.2 million gallons of contaminated groundwater per day. The treated groundwater is blended in the City of Glendale reservoir and into the city's water distribution system for residential and drinking water use. This water treatment facility is one of the first large-scale VOC removal plants in southern California and is the first project in California to be permitted under the state's policy 97-005 for domestic use of extremely impaired sources.
7	Industrial Reuse of Treated Groundwater at an Aerospace Facility	VOCs	Regional Water Quality Control Board, local municipality	A groundwater pump-and-treat system was designed that operates with two extraction schemes (high concentration and low concentration), two treatment systems (carbon filtration and oxidation), and on-site reuse of the water treated by the carbon filtration system (primarily in cooling towers). Reuse also allowed reduction of both the flow to the publicly owned treatment works and the demand for scarce potable water supplies.

TABLE 5 – Summary of Water Conservation and Treated Groundwater Reuse Case Studies

Case Study Number	Case Study Title	Contaminants of Concern	Regulatory Regime and/or Permitting	Summary
8	Treated Groundwater Reinjection at a Former Fast Fuel Facility	VOCs	Regional Water Quality Control Board	A pump-and-treat system was implemented to address groundwater impacts at this site. The system treated the extracted groundwater and disposed of it via the sanitary sewer system. After regulatory approval, treated groundwater was reinjected into the aquifer via a monitoring well installed for this purpose. Over three years, 29.9 million gallons of treated groundwater was reinjected into the aquifer.
9	Reuse of Groundwater for Industrial Process Water Supply	VOCs	State environmental agency	At this site, contaminated groundwater is extracted and pumped directly into the steel mill contact cooling water system where the VOCs are volatilized. Four billion gallons of water is conserved by avoiding the use of clean water for cooling water. Ultimately, after the groundwater has cycled through the cooling process, it is discharged to a nearby river.
10	Groundwater Recirculation at a Railyard Facility	VOCs	State environmental agency	At this site, a temporary groundwater recirculation system induced anaerobic reductive dechlorination via injection of a soluble electron donor source (i.e., dextrose and nutrients). Recirculated aquifer water was used for the substrate injection and system operation. Over 2 million gallons of water was reused for substrate delivery instead of discharge to the storm drain or sanitary sewer.
11	Treated Ground-water Reuse at a Former Marine Corps Air Station	VOCs	Regional Water Quality Control Board, EPA	Two groundwater pump-and-treat systems operate at this site. Over 86% of the extracted water from the two systems is reused for nonpotable purposes (largely irrigation); the remaining 14% is discharged to the Aliso Creek Ocean Outfall.
12	Orange County Water District's (OCWD's) Groundwater	1,4-Dioxane; NDMA	Regional Water Quality Control Board, state department of	The GWRS treats 70 million gallons per day (mgd) of secondary-treated wastewater effluent from the Orange County Sanitation District through a three-step purification process. An average of 30 mgd treated water is injected into coastal aquifers, and the remaining treated water is

TABLE 5 – Summary of Water Conservation and Treated Groundwater Reuse Case Studies

Case Study Number	Case Study Title	Contaminants of Concern	Regulatory Regime and/or Permitting	Summary
	Replenishment System (GWRS)		health, local municipality	conveyed 13 miles to percolation ponds to replenish other areas of the groundwater basin. The GWRS produces sufficient potable water to supply 600,000 Orange County residents.
13	Recycled Water Irrigation and Groundwater Study, Santa Clara Valley Water District	VOCs, NDMA, HAAs, PFCs	Regional Water Quality Control Board	This Water District conducted a recycled-water irrigation and groundwater study to evaluate the potential effects of recycled water used for irrigation on groundwater quality and identify best management practices to protect groundwater quality. Initial study results indicate that recycled water can be used for irrigation purposes without significant degradation of the groundwater. Additional long-term monitoring is being conducted.
14	Treated Ground-water Irrigates On-Site Golf Course at Former Carswell Air Force Base	VOCs	Superfund, state environmental agency	Treated groundwater from a pump-and-treat system was reused to irrigate an on-site golf course. The system recovered water at an average rate of 100 gpm. Prior to this reuse application, water was transported to the site via trucks. The reuse resulted in increased flow in an intermittent stream and improved the water quality of the stream and irrigation pond.

Notes:
EPA = Environmental Protection Agency
gpm = gallons per minute
HAAs = haloacetic acids
mgd = million gallons per day
NDMA = nitrosodimethylamine
PFCs = perfluorochemicals
VOCs = volatile organic compounds

CLOSING THOUGHTS

The remediation industry is a multi-billion dollar per year sector of the U.S. economy (Farkas and Frangione, 2010), and much of that expenditure is for remediating groundwater contamination. Given that such vast amounts of money are spent – at individual sites, not to mention collectively over all sites – in remediating a vital resource, it seems incumbent on all parties to try to reuse that same resource as much as possible.

In the case of contaminated groundwater, this boils down to first of all giving careful consideration to in-situ remedies that allow for eventual groundwater use as well as treated groundwater reuse. These approaches to remediation are inherently more sustainable than other approaches that make little, if any, use of the very resource that is being restored.

As evidenced by the case studies presented herein, efforts are underway in the U.S. and other countries to increase the service life of groundwater associated with cleanups. Many efforts are encouraged by the economics of treated water reuse, but many appear to be motivated by the perception that water is inherently valuable. In short, people seem to be asking the logical question, *"Why expend effort, expense, and energy to clean up a resource and then discard it to a storm drain or sewer without at least trying to reuse it?"*

When integrating groundwater conservation and reuse into remediation, challenges such as water quality impacts and water balance and availability exist. Beyond these limits, public perception and liabilities (actual and perceived) influence the nature and scope of remediation. These barriers of a human kind seem most amenable to being solved, and are worthy of further effort by others in the remediation business.

Despite these challenges, a grass roots effort appears to be underway to "do the right thing" and make every effort to utilize groundwater. Much of the history of "doing the right thing" with water is grounded in the wastewater industry where, in some jurisdictions, efforts have assured the reuse of vast amounts of public wastewater – sometimes by injection into drinking water aquifers. Clearly the history, experience, and precedence of the wastewater industry in reusing treated wastewater should be leveraged when working to integrate treated groundwater reuse into remediation.

As evidenced in the case studies herein, groundwater conservation and reuse can be a desirable and necessary attribute of any remedy. Depending on the importance of groundwater in a particular area, the function and services provided by groundwater should be considered. Although a complete and quantitative sustainability analysis of a water reuse project can be complex and estimating impacts to the triple bottom line is complicated by the site-specific nature of remediation and its associated uncertainties, the information provided in the case studies could provide a basis for further research in the development of qualitative and quantitative metrics.

With the increase in global population and water demand, the application of groundwater conservation and reuse practices at remediation sites is imperative. It seems difficult to find a circumstance in which the discharge of treated water to a sewer or storm drain is more sustainable than reusing the water. Remediation practitioners should consider the advantages and disadvantages of remediation technologies with respect to water reuse and/or conservation, remediation duration, relative costs, and environmental footprint. But selecting a remedy is not the only way that remediation practitioners can conserve water. Water use can be minimized during remediation by reevaluating design and operation and maintenance practices. Although challenges persist, most can be overcome with additional planning and clear communication about expectations amongst all stakeholders. The extra work entailed is worth the effort to conserve and reuse our most vital resource: water.

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ABOUT THE CASE STUDIES

The members of SURF participating in this initiative identified case studies through their own experience, literature reviews, and referrals from colleagues and co-workers. Publicly available information for each case study was compiled and reviewed. Then, key individuals associated with each case study were contacted. These key individuals verified that the information was current and accurate and provided additional clarifications and insight. The resulting information was compiled into a matrix template intended to highlight potential topics of interest of remediation professionals considering water conservation and reuse. Although the case studies presented herein may represent work undertaken more than a few years ago, the principles, techniques, and approaches used can be applied to remediation projects today.

Water Conservation & Reuse Case Study #1

Case Study Name & Description	San Francisco Bay Area Survey of Treated Groundwater Reuse
Location	This case study includes sites in Alameda, Contra Costa, San Francisco, Santa Clara (north of Morgan Hill), San Mateo, Marin, Sonoma, Napa, and Solano counties. The six sites that are reusing treated groundwater are located in Santa Clara County.
Background & Drivers	An evaluation of treated groundwater reuse was performed in 2010 and updated in 2012. All sites included in the evaluation are permitted under Regional Water Quality Control Board San Francisco Bay Region Order No. R2-2009-0059: (NPDES No. CAG912003), which includes standard language requesting reuse evaluation; however, reuse is not documented or tracked. Data used in the survey was based on publically available information from the Geotracker website and interviews with the appropriate Regional Water Quality Board and dischargers. The following information was obtained: • Extraction rates • Reuse rates • Types of reuse • Discharge location • Water quality Sites that reused treated groundwater were identified, and specific sites were selected to be interviewed to determine commonalities or barriers to reuse.
Contaminants of Concern	VOCs
Volume of Water and/or Flow Rate	Updated 2012 survey results show that six of 49 operating groundwater treatment facilities reuse treated groundwater. Of the 49 operating facilities, total extracted groundwater volume is greater than 1.4 billion gallons/year, with about 275 million gallons/year reused (approximately 20% reuse).
Regulatory Regime and/or Permitting	All sites included in the evaluation are permitted under a general VOC discharge permit (NPDES No. CAG912003), which requires that discharges coordinate with the appropriate Regional Water Quality Control Board and local agencies for reuse. For facilities within its jurisdiction, the Santa Clara Valley Water District has a financial incentive for reinjection at sites meeting specific criteria (i.e., groundwater production fees are reimbursed). To qualify for the reimbursement, the site must have reuse a minimum volume of 25 acre feet per year, reinject the extracted treated groundwater into the same aquifer, and demonstrate that higher priority uses (including irrigation) are not feasible.
Barriers	Survey results indicate the following primary barriers to treated groundwater reuse: • Financial and regulatory incentives • Infrastructure requirements • Long-term reliable supply • Water quality and/or pretreatment Survey results indicate that the following characteristics are present at sites reusing treated groundwater: • Significant quantities of treated groundwater available • Reliable long-term supply and treatment system operation • Financial incentives to reuse or reinject • Partnering of several nearby dischargers

Water Conservation & Reuse Case Study #1

Case Study Name & Description	**San Francisco Bay Area Survey of Treated Groundwater Reuse**
	• Favorable local Infrastructure
Reuse Application	Six sites are reusing groundwater for the following purposes: reinjection (one site), industrial supply (three sites), decorative pond (one site), and irrigation (one site). By far, reinjection accounts for the largest volume of reuse with 260 million gallons per year.
Cost	Not evaluated.
References	http://geotracker.waterboards.ca.gov Byler, T.; S. Bourne; A. Petti; M. Cunningham. 2010. *Treated Groundwater Reuse from Site Remediation in the San Francisco Bay Area*. Proceedings from Groundwater Resources Association of California, 19th Annual Meeting "Thinking Outside the Pipe: Exploring and Protecting Local Water Supplies." September 15-16.
SURF Interpretation / Synopsis: **Only 20% of the sites in the San Francisco Bay Area are reusing treated groundwater. Of the sites reusing treated water, reuse via reinjection accounts for the largest volume.**	

Water Conservation & Reuse Case Study #2

Case Study Name & Description	**Treated Groundwater Reuse at United Technologies Corporation (UTC) Former Missile Propulsion Testing Facility**
Location	This site is located in San Jose, California and occupies 5,113 acres in unincorporated Santa Clara County.
Background & Drivers	The site has been reusing treated groundwater since 1991 for irrigation and dust control. In the past (such as during extended droughts), treated groundwater was also allowed to be used for dust control at nearby off-site areas such as a county motorcycle park and a country club. At the site, creeks provide a pathway for potential contaminant transport to a downstream reservoir. Site institutional controls limit human consumption of on-site creek water, and deed restrictions limit usage of some on-site areas. VOCs were detected in on-site creeks and were primarily the result of contaminant transport from surface soil via stormwater runoff and groundwater discharge. Based on these results, the frequency of surface water monitoring was increased to evaluate the stream VOC levels and potential impacts. VOCs were not detected in surface water at concentrations that threaten aquatic organisms.
Contaminants of Concern	VOCs; polychlorinated biphenyls (PCBs); total petroleum hydrocarbon (TPH); perchlorate; and 1,4-dioxane
Volume of Water and/or Flow Rate	Based on an annual environmental monitoring report, extracted groundwater totaled 21 million gallons in 2012.
Regulatory Regime and/or Permitting	The site is permitted under the San Francisco Bay Regional Water Quality Control Board (SF RWQCB Order No. R2-2012-0019) Water Reclamation: California Water Code (CWC) Section 13512. The permit includes numerical limits for VOCs, semivolatile organics, PCBs, TPH, and perchlorate in treated groundwater that is reused, along with other requirements for on-site reuse. Two other significant California codes impacted the ability to reuse water at this site: 1. California Water Code (CWC) Section 13512 which includes state policy to promote the use of recycled to help meet water needs 2. California State Water Board Resolution No. 88-160 which allows discharges of extracted, treated groundwater from site cleanups to surface waters only if it has been demonstrated that neither reclamation nor discharge to the sanitary sewer is technically and economically feasible.
Barriers	Not evaluated.
Reuse Application	Water treated at the on-site groundwater treatment plant is routed directly to two on-site storage ponds to help manage water levels. To maintain 2 feet of freeboard space in the ponds, the treated groundwater is periodically sprayed on nearby landscaping and pastures without causing surface water runoff.
Cost	Not evaluated.
References	Keith Roberson, SF RWQCB, 510.622.2404, keith.roberson@waterboards.ca.gov SF RWQCB Order No. R2-2012-0019, Revision of Final Site Cleanup Requirements and Rescission of Order No. R2-2004-0032 for United Technologies Corporation. State Water Board Resolution No. 88-160, San Francisco Bay Regional Water Quality Control Board Position on the Disposal of Extracted Groundwater from Groundwater Cleanup Projects. California Water Code (CWC) Section 13512, Includes State Policy Related to Water Recycling.

<u>SURF Interpretation / Synopsis</u>: Treated groundwater is discharged to storage ponds and then used for spray irrigation, dust

Water Conservation & Reuse Case Study #2

Case Study Name & Description	Treated Groundwater Reuse at United Technologies Corporation (UTC) Former Missile Propulsion Testing Facility
control, or soil compaction for a construction site. In the past, off-site water reuse was allowed during periods of extended drought. Surface water creek monitoring is required.	

Water Conservation & Reuse Case Study #3

Case Study Name & Description	**Water Reuse at the Former Unidynamics Superfund Site**
Location	This site is located in Goodyear, Arizona.
Background & Drivers	This site is located in Central Arizona within the Sonoran Desert, an area with a total average annual rainfall of approximately 8 inches. Water pumped from the aquifer within this arid environment is a precious resource. Groundwater cleanup began in 1994, with the installation of groundwater pump-and-treat systems. Five of these systems operate at the site and receive contaminated groundwater from 13 extraction wells.
Contaminants of Concern	VOCs, consisting primarily of trichloroethene (TCE), acetone, and methyl ethyl ketone (MEK)
Volume of Water and/or Flow Rate	The aggregate flow from the extraction wells is approximately 2,800 gpm.
Regulatory Regime and/or Permitting	As a Superfund site, this site is exempt from many of the water rights laws and permitting requirements that would normally be associated with pumping groundwater and distributing for irrigation use in the state of Arizona.
Barriers	Not evaluated.
Reuse Application	This site achieves 100% reuse of treated groundwater. Approximately 1,600 gpm (about 57%) of remediated groundwater is returned back to the aquifer through a series of 12 injection wells. The remainder of the remediated groundwater (approximately 1,200 gpm) (about 43%) is used for dust control, cooling water, and irrigation of local agriculture and a golf course.
Cost	Not provided; however, the reuse of treated groundwater by the school as cooling water reduces the school's heating and cooling costs by an estimated 40%.
References	http://yosemite.epa.gov/r9/sfund/r9sfdocw.nsf/vwsoalphabetic/phoenix-goodyear+airport+area?opendocument
SURF Interpretation / Synopsis: **At this site, 100% of the treated groundwater is reused, either through reinjection, cooling water, irrigation, or dust control.**	

Water Conservation & Reuse Case Study #4

Case Study Name & Description	**Treated Groundwater Reused as Drinking Water at Superfund Site in Nebraska**
Location	This Superfund site is located in a city in east-central Nebraska.
Background & Drivers	This site contains a VOC-contaminated groundwater plume beneath commercial and residential properties in the southwest, central, and north-central portion of the city. Groundwater cleanup began in 2004, with the installation of a groundwater extraction and treatment system that is used to intercept the groundwater plume and treat it using a packed column air stripper. The treated groundwater either is discharged to the city for drinking water use or, in periods of low drinking water demand, is discharged to surface water bodies via the city's storm sewer.
Contaminants of Concern	VOCs, consisting primarily of tetrachloroethene (PCE) and trichloroethene (TCE)
Volume of Water and/or Flow Rate	The average flow rate of the groundwater extraction and treatment system is approximately 1,400 gallons per minute, which is equivalent to 2 million gallons per day.
Regulatory Regime and/or Permitting	This site is regulated by the Environmental Protection Agency, Nebraska Department of Environmental Quality, and Nebraska Health & Human Services System.
Barriers	Not evaluated.
Reuse Application	Treated groundwater is reused as drinking water rather than discharging treated groundwater solely to a storm sewer or conveying it to a wastewater treatment plant. Reused water in the area has become a considerable asset. In three years, nearly 800 million gallons of treated groundwater water has been provided as drinking water to the city.
Cost	Not evaluated.
References	Schlebusch, M. and L. Splichal. 2009. *Design, Construction, and Operation of a Groundwater Extraction and Treatment System for a Potable Water Supply.* Proceedings of the 2009 World Environmental and Water Resources Congress, held in Kansas City, Missouri, May 17-21, 2009. Schlebusch, M. and L. Splichal. 2009. 23rd Annual Water Reuse Symposium.
SURF Interpretation / Synopsis: A majority of the treated groundwater is reused as drinking water. During periods of high drinking water demand, the city uses nearly 100% of flow from the treatment system. The remainder of the treated groundwater is discharged to the city's storm sewer system.	

Water Conservation & Reuse Case Study #5

Case Study Name & Description	**Hydraulic Containment and Reinjection System for Treatment of Groundwater VOCs**
Location	The Kearny Flagpole site is located in Stockton, California.
Background & Drivers	The volatile organic compounds (VOCs) tetrachloroethene and trichloroethylene were discovered near several city water supply wells. At this chlorinated solvent release site, a hydraulic containment and reinjection system is used to contain a groundwater VOC plume and protect drinking water. Before 1,4-dioxane, a chlorinated solvent stabilizer, was discovered at the site, granular activated carbon and air stripping was used to remove VOCs from groundwater. Because these systems are not effective in removing the hydrophilic contaminant 1,4-dioxane, UV/H_2O_2 oxidation was used to degrade the 1,4-dioxane. In its first 18 months of operation, the UV/H_2O_2 oxidation system reduced 1,4-dioxane concentrations from 110 parts per billion (ppb) to below 1.0 ppb.
Contaminants of Concern	VOCs, including tetrachloroethene (PCE), trichloroethene (TCE), and 1,4-dioxane
Volume of Water and/or Flow Rate	The average flow rate of the groundwater containment/reinjection system is 200 gpm.
Regulatory Regime and/or Permitting	This site is regulated by the California Department of Health Services (setting 1,4-dioxane action level at 1ppb) and the Environmental Protection Agency.
Barriers	1,4-dioxane is miscible in water, has a low affinity for carbon materials, does not readily biodegrade and is a possible human carcinogen creating multiple challenges for removal of 1,4-dioxane to safe levels.
Reuse Application	This site achieves 100% reuse of treated groundwater through reinjection into the subsurface.
Cost	Not evaluated.
References	Festger, A.D. 2003. "UV Oxidation Applied to Remove 1,4-Dioxane at California VOC Remediation Site." *Southwest Hydrology Magazine*. May/June:8, 27. Tom Mohr, tmohr@The14DioxaneBook.com
SURF Interpretation / Synopsis: At this site, 100% of the treated groundwater is reused through reinjection into the subsurface.	

Water Conservation & Reuse Case Study #6

Case Study Name & Description	**Glendale Water Treatment Facility: Remediated VOC Groundwater for Residential and Drinking Water Use**
Location	This site is located in Glendale, California, which is in Los Angeles County.
Background & Drivers	In 1980, concentrations of chlorinated volatile organic compounds were detected above regulatory levels in some of the production wells for the City of Glendale and Los Angeles. The shutdown of these wells represents the loss of a substantial drinking water source. In 2000, a 5,000 gpm treatment plant began operation in the City of Glendale. The City of Glendale operates the treatment plant and associated wells, which includes seven 200-foot wells, one 400-foot well, three miles of pipeline, and an air stripping and liquid phase granular activated carbon facility to remove VOCs in groundwater. Due to increasing chromium concentrations in the treatment plant effluent, the City of Glendale developed a program to evaluate chromium treatment alternatives and technologies. Weak-based anion exchange (WBA) and reduction, coagulation, and filtration were selected as alternatives for pilot- and demonstration-scale testing. The demonstration-scale testing program was completed in 2012, and the WBA system continues to operate.
Contaminants of Concern	Chlorinated VOCs, including trichloroethene (TCE) and tetrachloroethene (PCE), and chromium
Volume of Water and/or Flow Rate	The facility remediates approximately 7.2 million gallons of contaminated groundwater per day.
Regulatory Regime and/or Permitting	Environmental Protection Agency (EPA), State of California Department of Public Health, and the City of Glendale
Barriers	Not evaluated.
Reuse Application	The treated groundwater is blended in the City of Glendale reservoir and into the city's water distribution system for residential and drinking water use. This water treatment facility is one of the first large-scale VOC removal plants in southern California and is the first project in California to be permitted under the state's policy 97-005 for domestic use of extremely impaired sources.
Cost	$18.5 million
References	Information provided by documents submitted to the EPA and the EPA website: http://yosemite.epa.gov/r9/sfund/r9sfdocw.nsf/3dec8ba3252368428825742600743733/33e2071f3f682bf988257007005e9429!OpenDocument
SURF Interpretation / Synopsis: **Contaminated groundwater is remediated and sent directly to the city's water distribution system, demonstrating the use of "clean" water in an area where the water supply is limited.**	

Water Conservation & Reuse Case Study #7

Case Study Name & Description	**Industrial Reuse of Treated Groundwater at an Aerospace Facility**
Location	This site is located in Huntington Beach, California.
Background & Drivers	Because the project is located in a drought-prone, semi-arid region of Southern California with limited water resources, water conservation was a priority in planning and operating the pump-and-treat system. A groundwater pump-and-treat system was designed that operates with two extraction schemes (high concentration and low concentration), two treatment systems (carbon filtration and oxidation), and on-site reuse of the water treated by the carbon filtration system (primarily in cooling towers). Water conservation and reuse principles were integrated into the design phase to maximize the amount of water extracted and treated groundwater used at the site in industrial processes and to provide flexibility for future reuse options.
Contaminants of Concern	VOCs
Volume of Water and/or Flow Rate	The system reuses approximately 80,400 gallons per day, more than 100 gpm.
Regulatory Regime and/or Permitting	Regional water quality control board, local water resources agency, and the sanitary district provided permitting and capital cost offsets.
Barriers	None - All parties were receptive in collaborating and working toward a more environmentally sustainable system that reduced the overall demand for water in a water-scarce area.
Reuse Application	Reuse primarily involves cooling tower water, but other options can be taken advantage of through a flexible design. Reuse allowed reduction of both the flow to the publicly owned treatment works and the demand for scarce potable water supplies. In addition, 110 metric tons of greenhouse gas emissions were avoided by selecting the appropriate treatment systems.
Cost	Not evaluated.
References	Patrick Keddington, Haley & Aldrich, (619) 285-7107

SURF Interpretation / Synopsis: Treated groundwater was reused by segregating 'high' and 'low' concentration groundwater streams, tailoring the treatment system to each stream, and providing flexibility in reuse, resulting in cost savings, reduced greenhouse gas emissions, and a benefits to the nearby community. The payback period of three to five years speaks to the good business sense this more sustainable approach represents.

Water Conservation & Reuse Case Study #8

Case Study Name & Description	**Treated Groundwater Reinjection at a Former Fast Fuel Facility**
Location	This site is located in North Hollywood, California
Background & Drivers	A groundwater monitoring well network composed of 27 wells was used since 1999 to assess potential groundwater impacts at this site. A groundwater plume extending off-site containing primarily fuel constituents was identified and treated using a groundwater recovery system. By April 2010, no fuel constituents were detected in the on- and off-site groundwater monitoring well network.
Contaminants of Concern	Fuel constituents, including gasoline; benzene, toluene, ethylbenzene, and xylenes (BTEX), methyl tert-butyl ether (MTBE), and di-isopropyl ether (DIPE)
Volume of Water and/or Flow Rate	Over three years, the system operated at a maximum rate of 40 gpm, removing and treating approximately 43.4 million gallons of groundwater
Regulatory Regime and/or Permitting	The Regional Water Quality Control Board provided oversight and issued General Waste Discharge Requirements for Biologically Activated Granular Carbon (CO No. 8907; Order No. R4-2005-0030).
Barriers	Not evaluated.
Reuse Application	A pump-and-treat system was implemented to address groundwater impacts. The system used granular activated carbon vessels colonized with native MTBE-degrading bacteria and amended with oxygen to treat the extracted groundwater and disposed of water via the sanitary sewer system. After approval by the Regional Water Quality Control Board, treated groundwater was reinjected into the aquifer via a monitoring well installed for this purpose. Water was diverted to the sewer in case of a power interruption. Over three years, 29.9 million gallons of treated groundwater was reinjected into the aquifer.
Cost	Not evaluated.
References	http://geotracker.waterboards.ca.gov Fast Fuel Facility 11051 Victory Blvd. North Hollywood, CA 91606 Case Number: T0603702602

SURF Interpretation / Synopsis: This project highlights the reinjection of biologically treated groundwater as a mitigation technique that reduces aquifer impacts normally associated with the removal, treatment, and subsequent discharge of large volumes of water to external sources.

Water Conservation & Reuse Case Study #9

Case Study Name & Description	**Reuse of Groundwater for Industrial Process Water Supply**
Location	This site is located in northeastern Ohio.
Background & Drivers	The site remediation plan required the isolating oil-impacted soil using an asphalt cap and installing eight recovery wells to extract free-phase oil, intercept and remove dissolved VOCs in groundwater, and prevent migration to off-site downgradient areas.
Contaminants of Concern	Dissolved VOCs and oil
Volume of Water and/or Flow Rate	The remediation system operates at approximately 1,000 gallons per minute and has recovered over 4,000 pounds of dissolved VOCs and about 6,000 gallons of oil.
Regulatory Regime and/or Permitting	Ohio Environmental Protection Agency
Barriers	Not evaluated.
Reuse Application	The extracted groundwater is pumped directly into the steel mill contact cooling water system, where the VOCs are volatilized in the steel cooling process. If the extracted groundwater from the remediation system was not added to the contact cooling water supply for the steel mill, the mill would have to obtain clean water for cooling from a separate well field used for process water supply. Four billion gallons of water is conserved by avoiding the use of clean water for cooling water. Ultimately, after the groundwater has cycled through the cooling process, it is discharged to a nearby river.
Cost	Not evaluated.
References	David Shea, dshea@sanbornhead.com

SURF Interpretation / Synopsis: Contaminated groundwater is extracted and used directly as process cooling water, which conserves the use of "clean" water. In addition, the energy and materials needed to treat the contaminants are reduced because the contaminants volatilize during the cooling process.

Water Conservation & Reuse Case Study #10

Case Study Name & Description	**Groundwater Recirculation at a Railyard Facility**
Location	Union Pacific Railroad Company's Railyard Facility in Eugene, Oregon.
Background & Drivers	At this site, VOCs are present in the groundwater and have migrated off-site to the northwest and north of the railyard. In May 2005, initial interim measures were completed to enhance in-situ bioremediation of chlorinated VOCs in two areas of the site. The initial interim measures consisted of a temporary groundwater recirculation system that induced anaerobic reductive dechlorination via injection of a soluble electron donor source (i.e., dextrose and nutrients). Chlorinated solvent concentrations decreased 90% within six months. In the six years following the 83-day recirculation treatment, chlorinated solvent concentrations have continued to decrease with no rebound.
Contaminants of Concern	Tetrachloroethene (PCE), trichloroethene (TCE), dichloroethene (DCE), vinyl chloride, trichloroethane (TCA), dichloroethane (DCA)
Volume of Water and/or Flow Rate	The remediation system operated at an average flow rate of approximately 40 gpm.
Regulatory Regime and/or Permitting	Work was performed with oversight from the Oregon Department of Environmental Quality, and the site obtained an Oregon State Underground Injection Control Permit.
Barriers	Not evaluated.
Reuse Application	Recirculated aquifer water was used for the substrate injection and system operation. Over 2 million gallons of water was reused for substrate delivery instead of discharge to the storm drain or sanitary sewer.
Cost	The remedy cost $270,000 or $3/cubic yard.
References	Eric Bueltel, ETEC, (971) 222-3616 www.deq.state.or.us/lq/cu/wr/UPRREugene/ExpandedIRAM.pdf

SURF Interpretation / Synopsis: Millions of gallons of water were reused for substrate delivery instead of discharge to the storm drain or sanitary sewer, representing a clear example of a best management practice when implementing an in-situ recirculation remedy.

Water Conservation & Reuse Case Study #11

Case Study Name & Description	Treated Groundwater Reuse at a Former Marine Corps Air Station
Location	This site is located on and adjacent to the former El Toro Marine Corps Air Station in Irvine, Orange County, California.
Background & Drivers	This site includes an area of shallow groundwater contamination (known as Site 24, near the source of contamination with higher concentration) and a downgradient area with lesser contamination (known as Site 18). At Site 24, remediation involves an active groundwater extraction network of 43 wells, groundwater treatment (air stripping followed by activated carbon filtration of the air stream), and discharge into a sewer that takes the (saltier) water to the ocean. At Site 18, one extraction well sends water for treatment with an air stripper and activated carbon. Typically, this greater volume of (non-salty) water is conveyed to the non-potable (i.e., irrigation) water distribution network.
Contaminants of Concern	Trichloroethene (TCE) and other VOCs
Volume of Water and/or Flow Rate	The downgradient extraction flow rate from Site 18 (principal aquifer, deeper wells) is typically 2,500 to 2,600 gpm. The flow rate of the on-site (source area, Site 24) extraction averages 390 gpm.
Regulatory Regime and/or Permitting	The former Marine Corps Air Station El Toro is a Superfund site, and cleanup is the responsibility of the Department of the Navy. The Santa Ana Regional Water Quality Control Board, California Department of Toxic Substances Control, and EPA Region 9 provide oversight. In addition, the Orange County Water District and Irvine Ranch Water District participate cooperatively in aspects of the cleanup. The Orange County Wastewater Authority's Aliso Creek Ocean Outfall is utilized for ocean discharge of some of the treated (saltier) groundwater after treatment.
Barriers	Not evaluated.
Reuse Application	In water-starved southern California, water reuse at this site is facilitated by the existence of a non-potable water distribution system. Over 86% of the extracted water from the two systems is reused for nonpotable purposes (largely irrigation); the remaining 14% is discharged to the Aliso Creek Ocean Outfall.
Cost	Not evaluated.
References	Arseny Kalinsky, Irvine Ranch Water District, 949.453.5867, kalinsky@irwd.com Eileen Mananian, California Department of Toxic Substances Control, 714.484.5359, Eileen.mananian@dtsc.ca.gov U.S. Department of Navy. 2008. *Fact Sheet: Installation Restoration Program, Sites 18 and 24 Groundwater Cleanup*. Former Marine Corps Air Station El Toro. August. Base Realignment and Closure, Program Management Office and Marine Corps Air Station, El Toro Installation Restoration Program. Irvine Ranch Water District. 2012. *Quarterly Groundwater Treatment System Monitoring Report, Installation Restoration Program Sites 18 and 24*. October. Prepared for the Department of the Navy Base Realignment and Closure Program Management Office West. Irvine Ranch Water District. 2012. *The Irvine Desalter Project: Site 18 – Principal Aquifer Update*. Presentation to the El Toro Remediation Advisory Board. April 25.

Water Conservation & Reuse Case Study #11

Case Study Name & Description	**Treated Groundwater Reuse at a Former Marine Corps Air Station**
	Irvine Ranch Water District. 2008. *Irvine Desalter Project*. August.

<u>SURF Interpretation / Synopsis</u>: This project highlights the benefit of having a nonpotable water distribution system available. In many cases, water extracted from cleanups is discharged to the sewer system for eventual transit to the ocean. In addition, this project highlights the benefits of cooperation among multiple levels of government – from local to federal – when conducting a remediation project.

Water Conservation & Reuse Case Study #12

Case Study Name & Description	Orange County Water District's (OCWD's) Groundwater Replenishment System (GWRS)
Location	This site is located in Talbert Gap in Huntington Beach, Orange County, California.
Background & Drivers	Growing populations and water scarcity in Orange County led to seawater intrusion into coastal aquifers and the closure of drinking water wells. As a result, direct aquifer injection was needed to create a hydraulic barrier and protect the county's primary potable water supply (500,000 acre-feet of usable water). The GWRS treats 70 million gallons per day (mgd) of secondary-treated wastewater effluent from the Orange County Sanitation District (OCSD) through a three-step purification process: microfiltration, reverse osmosis, and advanced oxidation UV/H_2O_2 treatment. This treatment is effective in removing trace organics and heavy metals. An average of 30 mgd is injected into coastal aquifers, while the remaining 40 million gallons per day are conveyed 13 miles to percolation ponds. In the ponds, the water infiltrates through gravel and sand beds to replenish other areas of the groundwater basin which provides a sustainable, indirect potable water source. The GWRS provides a significant reduction in greenhouse gas emissions and energy costs because it costs less than half of the energy currently required to import water from Northern California and one third the cost to desalinate water. The GWRS also reduces the amount of wastewater being discharged into the Pacific Ocean.
Contaminants of Concern	1,4-dioxane and N-nitrosodimethylamine (NDMA)
Volume of Water and/or Flow Rate	The current production capacity is 70 mgd (215 acre-feet per day) and a total production of 23.5 billion gallons (72,000 acre-feet) per year.
Regulatory Regime and/or Permitting	Santa Ana Regional Water Quality Control Board, California Department of Public Health (must maintain 1,4-dioxane below 1 micrograms per liter), OCWD, and OCSD.
Barriers	The following barriers existed when developing and implementing the groundwater replenishment system: public perception of wastewater reuse, risk of emerging contaminants in drinking water, and recalcitrant and highly soluble contaminants.
Reuse Application	This project features the sustainable reuse of the finite nonsaline water resources in a geographic location of intense water scarcity. The GWRS uses aquifer recharge to produce sufficient potable water to supply 600,000 Orange County residents. Scientific studies performed in the early 2000s concluded that the reused wastewater, after purification treatment, would actually "improve the groundwater basin's overall quality." Successful water reuse was achieved through: commitment to ongoing monitoring, an active engagement of the public and other stakeholders, and open dialogue about the contaminants and applied treatment technologies via the website and public meetings.
Cost	The capital cost to build the GWRS was $481 million (U.S. Dollars) and was funded through $92.8 million in local, state and federal grants and the remaining $388 million was cost shared between OCWD and OCSD. The grant funding came from: California State Water Bond (Proposition 13), California Department of Water Resources, California State Water Resources Control Board, U.S. Bureau of Reclamation's Title XVI program, California Energy Commission, and Environmental Protection Agency.
Reference	http://www.gwrsystem.com/ Roy Herndon, OCWD

Water Conservation & Reuse Case Study #12

Case Study Name & Description	Orange County Water District's (OCWD's) Groundwater Replenishment System (GWRS)
	(714) 378-3200 rherndon@ocwd.com

SURF Interpretation / Synopsis: The groundwater replenishment system at this site provides a local additional source of 70 mgd of reliable, high quality, potable water; protects the groundwater basin from seawater intrusion; and reduces the amount of wastewater being discharged into the Pacific Ocean—all outcomes that are widely supported by the local community.

Water Conservation & Reuse Case Study #13

Case Study Name & Description	**Recycled Water Irrigation and Groundwater Study, Santa Clara Valley Water District**
Location	The field study site is located within the Santa Clara Valley Water District in San Jose, California.
Background & Drivers	The Santa Clara Valley Water District conducted a recycled water irrigation and groundwater study from October 2008 to March 2010. The goal of this study was to evaluate the potential effects of recycled water used for irrigation on groundwater quality and identify best management practices to protect groundwater quality. The study included laboratory testing of soil irrigated with recycled water and an 18-month field study at a site using recycled water for irrigation. The study consisted of the following five phases: (1) recycled water literature review and data analysis (2) numerical soil attenuation model and bench-scale testing (3) pilot-scale study of irrigation using tertiary-treated recycled water from San Jose (4) evaluation of potential impacts (5) proposed recycled water irrigation screening levels, best management practices, and ongoing monitoring
Contaminants of Concern	Over 40 compounds were monitored, from pH to fecal coliform to carbon tetrachloride. VOCs and other typical environmental contaminants were not consistently detected. N-nitrosodimethylamine (NDMA), haloacetic acids (HAAs), and perfluorochemicals (PFCs) were of greatest concern due to their absence in baseline tests and presence at low levels in shallow groundwater after recycled water irrigation began. These constituents were present in the recycled water applied for irrigation, but the groundwater concentrations were significantly lower, likely due to volatilization in the vadose zone and/or biotransformation in the soil.
Volume of Water and/or Flow Rate	Approximately 23 acre-feet of water was applied to the study area. Significantly less irrigation water was used in the winter months than in the summer months.
Regulatory Regime and/or Permitting	Tertiary treated water used for irrigation was produced by the South Bay Water Recycling Program and applied by the site owner in accordance with Regional Water Quality Control Board requirements. The study was not subject to regulatory requirements.
Barriers	Not evaluated.
Reuse Application	Based on the report, initial study results indicate that recycled water can be used for irrigation purposes without significant degradation of the groundwater. However, additional long-term monitoring is being conducted. Proposed recycled water irrigation screening levels (PRWISLs) and best management practices were developed for tested constituents.
Cost	Not evaluated.
References	http://www.valleywater.org/Services/GroundwaterStudies.aspx

<u>SURF Interpretation / Synopsis</u>: The study indicated that areas where groundwater is shallow and lacking in significant clay deposits are more susceptible to emerging constituents such as NDMA which is highly mobile in groundwater. Evaluation using screening techniques similar to the PRWISLs can be used where treated water is reused to identify potential risks to groundwater sources.

Water Conservation & Reuse Case Study #14

Case Study Name & Description	**Treated Groundwater Irrigates On-Site Golf Course at Former Carswell Air Force Base**
Location	The site is located in Fort Worth, Texas, and Landfills 4 and 5 are located on the east side of the site.
Background & Drivers	A pump-and-treat system was installed as an interim remedial measure to intercept a chlorinated solvent plume migrating toward the site boundary. At the same time, a private operator of a former golf course on-site needed a more reliable water source for irrigation.
Contaminants of Concern	Trichloroethene (TCE) and its daughter products
Volume of Water and/or Flow Rate	The system recovered water at an average rate of 100 gallons per minute (gpm).
Regulatory Regime and/or Permitting	The site is on the National Priorities List; therefore, a formal National Pollutant Discharge Elimination System (NPDES) permit was not required. A surface water discharge agreement was given to the Air Force based on a review of a surface water discharge application following the NPDES process. The equivalent of a NPDES permit application was used as a way to document the approach. Other agencies involved were as follows: EPA Region VI and the Texas Commission on Environmental Quality
Barriers	Not evaluated.
Reuse Application	Treated groundwater was reused to irrigate an on-site golf course. Prior to this reuse application, water was transported to the site via trucks. System performance data and post air stripper carbon polishing ensured that the quality of the treated groundwater was appropriate for reuse. The reuse resulted in increased flow in an intermittent stream and improved the water quality of the stream and irrigation pond.
Cost	Before installation of the system, water was discharged to the local publicly owned treatment works at a cost of approximately $85,000/year in fees.
Reference	George Walters, Wright-Patterson Air Force Base, 937.255.3578
SURF Interpretation / Synopsis: **This site reused treated effluent from a pump-and-treat system as irrigation water instead of obtaining water from an off-site source.**	