



Dry Wells and the Risk of Groundwater Contamination: An Annotated Bibliography

December, 2014
Updated, December, 2016

Ecotoxicology Program
Pesticide & Environmental Toxicology Branch
Office of Environmental Health Hazard Assessment
California Environmental Protection Agency

This page left blank intentionally

Authors:

Hamad Hamad

Bennett Hughes Lock

Ary Ashoor

Nelson Pi

Rebecca Green

Emily Edwards

and

Barbara Washburn

This page left blank intentionally

Table of Contents

Glossary.....	1
INTRODUCTION	3
ARTICLES PERTAINING TO DRY WELLS AND THE RISK OF GROUNDWATER CONTAMINATION	5
Published between 2010 – present	5
Using Graywater and Stormwater to Enhance Local Water Supplies: An Assessment of Risks, Costs, and Benefits.....	5
Evaluation and Demonstration of Stormwater Dry Wells and Cisterns in Millburn Township, New Jersey	9
Expanding local water supplies: Assessing the impacts of stormwater infiltration on groundwater quality	11
Potential effects of roadside dry wells on groundwater quality on the Island of Hawai’i – Assessment using numerical groundwater models	13
The Los Angeles and San Gabriel Rivers Water Augmentation Study	15
Published Between 2000 - 2010	19
Decision Making Framework for Groundwater Protectiveness Demonstrations: Underground Injection Control System Evaluation and Response	19
Hydrogeology, water chemistry, and factors affecting the transport of contaminants in the zone of contribution of a public supply well in Modesto, eastern San Joaquin Valley, California.....	23
Influencing factors and a proposed evaluation methodology for predicting groundwater contamination potential from stormwater infiltration activities	27
Published Between 1990 - 2000	29
Groundwater contamination potential from stormwater infiltration practices	29
The impact of intentional stormwater infiltration on soil and groundwater	31
Evaluation of Urban Runoff Infiltration and Impact to Groundwater Quality in Park Ridge, Wisconsin	33
The Class V Underground Injection Control Study: Volume 3, Stormwater Drainage Wells.....	35
Pilot Evaluation Subsurface Stormwater Disposal Facilities	42
The groundwater recharge and pollution potential of dry wells in Pima County, Arizona	44
Published Between 1980 – 1990	46

The groundwater pollution potential of dry wells in Pima County, Arizona	46
Effect of urban storm water injection by Class V wells on the Missoula aquifer, Missoula, Montana	50
Additional case study simulations of dry well drainage in the Tucson basin	53
Urban stormwater injection via dry wells in Tucson, Arizona and its effect on groundwater quality	55
Case study simulations of drywell drainage in the Tucson basin	59
Articles of Related Interest	61
Artificial recharge of groundwater: hydrogeology and engineering	61
Estimation of groundwater recharge from precipitations, runoff into drywells, and on-site waste-disposal systems in the Portland basin, Oregon and Washington.....	62
Maintenance of stormwater BMPs in four Maryland Counties: a status report.....	64

Glossary

Alluvium: A deposit consisting of sand and/or mud formed by flowing water.

Below Land Surface (bls): The depth in feet or meters of groundwater, a dry well, a monitoring well, or similar devices below the surface of the ground.

Caliche: A deposit consisting of sand or clay impregnated with crystalline salts such as sodium nitrate or sodium chloride.

Class V Injection Wells: A system deeper than its width used to inject non-hazardous fluids underground. Dry wells are class V injection wells.

Drinking Water Equivalent Level (DWEL): The estimated exposure which is interpreted to be protective for non-carcinogenic endpoints of toxicity over a lifetime of exposure, as defined by U.S. EPA.

Infiltration Trench: A rock-filled trench with no outlet that receives stormwater runoff. Stormwater runoff passes through some combination of pretreatment measures, such as a swale and detention basin, and into the trench. There, runoff is stored in the void space between the stones and infiltrates through the bottom and into the soil matrix.

Lysimeter: A device for measuring the percolation of water through soils and for determining the soluble constituents removed in the drainage.

Maximum Contaminant Level (MCL): The maximum permissible concentration of a contaminant in a public drinking water system, as defined by California.

Piezometer: A device designed to measure the pressure of groundwater.

Public Health Goal (PHG): The concentration of a chemical contaminant in drinking water that does not pose a significant risk to health, as defined by OEHHA.

This page left blank intentionally

INTRODUCTION

This summary of scientific literature and reports has been prepared by staff of the Ecotoxicology Program at the Office of Environmental Health Hazard Assessment under an interagency agreement with the City of Elk Grove to investigate the risk of using dry wells, in conjunction with other stormwater infiltration practices, to groundwater quality. This survey was completed after three years of drought in California, at a time when there is great interest in identifying ways to treat stormwater as a resource to recharge aquifers. Numerous reports have been published recently documenting overdraft of groundwater and subsidence associated with aquifer depletion. Some communities in California depend solely on groundwater for their water needs. They are especially interested in identifying ways to manage their groundwater and stormwater in a sustainable fashion.

Stormwater and watershed managers at the same time are applying infiltration practices, called low impact development (LID) practices, to minimize the adverse effects of changes in the urban water cycle on the aquatic ecosystem. Stormwater not only introduces pollutants into waterways, but also scours the bed and banks of local waterways, degrading aquatic habitat. Runoff infiltration practices can reduce runoff volume, thereby mitigating the adverse impacts. But a constant challenge to stormwater engineers in achieving successful LID implementation are clay soils that serve as a barrier to infiltration.

Dry wells address both of the above issues – facilitating stormwater infiltration and recharging the aquifer. But a persistent concern remains: Will stormwater infiltration pollute groundwater? The purpose of this literature review has been to understand what others have learned from studying this question. Peer-reviewed scientific studies, graduate student theses, and government reports were used in preparing this review. This material was collected by conducting searches in the following databases: GeoRef (EBSCO), Engineering Village, Science Direct, PubMed, Civil Engineering Database, and Scopus. Searches included combinations of the keywords and phrases: dry well, dry well design, clogging, groundwater contamination, artificial recharge, stormwater injection, stormwater management, and runoff. The bibliography of each paper was scanned for additional relevant papers. The bulk of the articles and reports collected address the issue of groundwater contamination associated with dry well use. Also included are a small number of articles that focus on good management practices for siting and maintaining dry wells.

Most of the studies reached a common set of conclusions that can be summarized as follows:

- Dry wells do not appear to contribute to groundwater contamination, even after use for up to 50 years.
- Some type of vegetative or structural pretreatment should be incorporated into the design; it serves to prevent clogging of the dry well and sequester sediment and associated pollutants.
- Many contaminants, especially metals, are retained in the vadose zone.
- Organic contaminants are frequently degraded by bacteria in the vadose zone.
- Dry wells should not be sited where known toxic material is used or near public-supply wells.
- Runoff from rooftops appears to be the least-polluted stormwater from any source.

- Pollutants with high abundance in stormwater, high mobility in the vadose zone, and those that are highly water soluble pose the greatest risk to groundwater quality. An example of this is nitrate.

The summary of each study was organized similar to many scientific reports: the purpose, relevant background, the methods used, including information about dry well design, followed by a results/discussion section and the conclusion reached by the author(s). To help quantify the results, the chemical data in each study was sometimes compared to Maximum Contaminant Levels, Public Health Goals and Health Based Advisory Levels. An "OEHHA Note" was included after some of the summaries that discussed how the conclusions of the study were relevant to California. The length of each review varies, depending on the level of detail and length of the report or article. Major reports or theses were discussed in greater detail than shorter articles. In reviewing each report/article, descriptions were provided of some of the key issues under discussion today regarding dry well use. Some of these issues include the dry well design; use and type of pretreatment; siting of the dry well; and relationship between contaminant concentrations in stormwater, sediment around the dry well (vadose zone) or in a pretreatment facility, and groundwater. In addition, the last section of the literature review contains relevant information to the construction and operation of dry wells, independent of groundwater quality. This information might be of particular use to stormwater managers.

The reviews are presented in order from most recent to oldest. A hyperlink was included in the citation when the document was available online. The literature review will be updated as new information becomes available. Although exhaustive searches were performed to prepare this review, if you become aware of omissions, please contact us so we can expand this review. Please contact Barbara Washburn at barbara.washburn@oehha.ca.gov.

ARTICLES PERTAINING TO DRY WELLS AND THE RISK OF GROUNDWATER CONTAMINATION

PUBLISHED BETWEEN 2010 – PRESENT

Using Greywater and Stormwater to Enhance Local Water Supplies: An Assessment of Risks, Costs, and Benefits.

National Academies of Sciences, Engineering, and Medicine. 2015. Washington, DC: The National Academies Press. 420 p. Posted at: <http://www.nap.edu/21866>

Purpose

The National Academies of Sciences, Water Science and Technology Board formed a committee of experts from around the U.S. and abroad to study issues linked to the use of greywater and stormwater resources. The purpose of the report was to assess the costs, risks, benefits, and variety of practices associated with these alternative sources of water for irrigation and aquifer recharge.

Background

The U.S. has seen a recent increase in stormwater practices that recharge groundwater as well as a greater interest in the water treatment potential of infiltration and low impact development (LID) systems. In addition, an increasing number of states are beginning to assess stormwater as a resource that can increase local water supplies and, thus, water security. A lack of risk-based guidelines, limited documentation on costs and benefits, as well as concerns about the potential groundwater contamination associated with stormwater infiltration limit the expansion of these practices.

Methods

Technical literature, briefings, and meetings among experts on the NAS committee formed the basis for the information in the report. The committee received briefings from a range of experts, including water utilities practitioners, government and public health officials, non-governmental organizations (including public interest and industry groups), and academics. The report summarizes literature addressing capture and reuse systems ranging from household to regional scales, from across the nation and builds on previous work done by the Academies to assess urban water use and the potential for desalination to augment urban water supplies.

Results/Discussion

Adverse Effects of Urban Stormwater Runoff on Aquatic Habitat and Water Quality

Stormwater capture can reduce the harmful effects of urban runoff on the aquatic ecosystem. In urban areas, where much of the land surface is impervious, stormwater runoff is conveyed directly into surface water bodies, often in higher volumes with more intense peak flows than would occur naturally. The increased volume of runoff degrades stream habitat through the erosion of the banks and beds of waterways, which in turn causes sedimentation of the streambed and loss of riparian vegetation. The high volumes and intense peak flows can also lead to flooding. Stormwater infiltration and capture can mitigate these adverse effects. In addition, urban runoff commonly carries high concentrations of

chemical and microbial contaminants into streams because impervious surface layers prevent infiltration which would otherwise trap contaminants and filter runoff. Chemical contaminants can create a toxic environment for aquatic species. In addition, high levels of nitrogen, phosphorous, and sediment in stormwater runoff can lead to algal blooms, low dissolved oxygen, and reduced water clarity which can significantly impact aquatic species. By reducing overall runoff volume, stormwater infiltration and capture can help prevent pollution of surface waters and protect aquatic life.

Water Supply Reliability

Stormwater capture can improve water supply reliability. Water shortages across the country and concerns about the impacts of climate change and population growth on water availability are other factors driving local stormwater infiltration, capture, and use. Much of the west, southwest, and southeast are experiencing water shortages or drought. Population growth, redistribution of water resources to areas with shortages, and the effects of climate change in water scarce regions further aggravate these shortages. Stormwater capture and infiltration projects can significantly increase urban water supplies at both the neighborhood and regional scale and, subsequently, improve water supply reliability and security. This approach is especially important in arid climates where stormwater can be stored in aquifers throughout wet seasons for use during dry seasons or droughts. In addition, stormwater capture and infiltration increase water security by diversifying the water supply portfolio.

Common Stormwater Contaminants

Contaminants in stormwater are of particular concern if the runoff is used for aquifer recharge. This was assessed using data from the National Stormwater Quality Database. Pathogens are a common stormwater contaminant, including from roof runoff. Metals from roads and parking lots, including lead, iron, copper, zinc, and cadmium, are commonly detected. Median concentrations of iron exceeded the recommended drinking water standards, about 35% of lead observations exceeded the MCL, and values of arsenic and cadmium falling in the 95th percentile of samples were close to drinking water standards. Organic contaminants detected in stormwater samples (including organochlorine pesticides, PAHs, and PCBs) exceeded proposed human health drinking water quality criteria. Organic chemicals at these concentrations pose cancer risks with significant exposures when stormwater enters drinking water sources via groundwater recharge, and harm aquatic species. Taken together, the database suggested that numerous classes of contaminants, presented in a detailed table in the report, are frequently found in stormwater at concentrations that have the potential to place groundwater resources at risk.

Assessment of Groundwater Contamination Risks

Urban runoff has the potential to contaminate groundwater, especially if large volumes are infiltrated or injected into aquifers that are used for drinking water supplies. Factors that influence the risk of contamination include the pollutant concentration and solubility, permeability and character of the soil or infiltration media, biological activity in the subsurface, infiltration rate, and depth to the water table, to name a few. Contaminants that are soluble, relatively non-volatile, ionic, and non-sorbing pose a greater risk to groundwater than those that are hydrophobic. Groundwater contamination from polluted runoff is more likely in areas where with shallow groundwater and sandy soils or other coarse media because there is reduced opportunity for attenuation and filtration. In a study of 15 dry wells,

investigators found that percolation through gravel and a minimum of 4 feet of vertical separation from the water table did not change dissolved copper, lead, and zinc or *E. coli* and enterococci in groundwater. Another study sampled the groundwater beneath 16 detention basins with sandy, unconsolidated soils and concluded that sandy soils do not effectively attenuate chemical contaminants. Knowledge of both contaminant concentration and subsurface geology contribute to assessing the risk of groundwater contamination.

State of Practice and System Design

The current designs and regulation of stormwater infiltration systems in the U.S. may not adequately protect groundwater quality. Designs for large-scale, regional stormwater infiltration projects are still emerging. In addition, design and performance standards for many infiltration systems were developed to address stormwater regulatory drivers to protect surface water rather than the protection of groundwater quality, leaving open the possibility of groundwater quality degradation. The infiltration of organic contaminants and salts from highly urbanized areas into water supply aquifers is of high concern, and human pathogens may also be of concern depending on the infiltration site characteristics. Stormwater infiltration for groundwater recharge therefore necessitates careful design to minimize groundwater contamination risks. Careful source area selection and source control of pollutants can also mitigate risks to groundwater quality as well as improve system efficiency.

Legal and Regulatory Issues Relevant to Stormwater Capture

1. Water Rights

A majority of states regulate water allocation and determine water rights through either prior appropriation or riparian rights. Prior appropriation, the doctrine used by most western states, determines water use allocation based on the historical order in which water right were acquired. Large scale stormwater capture or the extensive use of small-scale stormwater capture systems could reduce flows into waterways and prevent downstream rights from being fulfilled. Explicit laws are rare and judicial interpretations of water rights are just beginning to be developed. Riparian rights, the second water rights doctrine, grants the land owners who border waterways the right to that water. Stormwater capture, use, and infiltration could reduce flows to waterways, thereby impacting downstream riparian rights.

2. Minimum Instream Flows

Sufficient instream flows must be maintained to protect aquatic habitat. Stormwater infiltration on the landscape upstream has the potential to reduce runoff into waterways. The extensive capture and use of stormwater and greywater may adversely affect these flows. In response to this concern, many states have adopted minimum instream flow laws in over-allocated basins to protect species and habitat.

3. Legislation That Encourages Infiltration Practices

Under the Clean Water Act, water quality standards set contaminant criteria to meet beneficial uses of water bodies and requires that a permit be obtained through the National Pollutant Discharge Elimination System (NPDES) in order to release pollutants into surface water. NPDES permits can include

requirements for stormwater management programs, which are increasingly emphasizing low impact development (LID) and “green infrastructure” implementation. Stormwater capture and use systems are consistent with these goals. In addition, the Underground Injection Control Program, implemented by the US EPA, provides guidance on how to design, site, and permit dry wells, with groundwater protection in mind.

Policy Implications

There is a lack of water quality standards or guidance for stormwater capture and use at the state and federal level. Regulations that do exist are often widely variable and too broad. The 2012 EPA Water Reuse Guidelines, for example, combines water uses with different concentrations of pollutants into one “urban use” category, resulting in overly protective criteria for stormwater infiltration (in contrast to release to surface waters). Risk-based guidance for stormwater that will be used for infiltration is needed to avoid overly restrictive policies. In addition, policy issues could arise when determining the siting of infiltration BMPs based on runoff source. For example, rooftop runoff commonly carries fewer contaminants than runoff from roads and parking lots, therefore policies restricting infiltration to roof runoff could arise. The costs and benefits of implementing more source control restrictions should be considered.

Conclusion

A growing interest in stormwater infiltration and LID has raised concerns about the potential for groundwater contamination, impacts to instream flows, and legal issues surrounding water rights. The lack of information on costs and benefits of implementing stormwater capture and reuse also hinders the expansion of such practices. With careful site selection and design, pretreatment features, source control, appropriate soil (or subsurface) composition, and adequate vertical separation from the water table, risk to groundwater quality can be substantially reduced. Legal issues surrounding the impact of infiltration and capture on water rights will arise more often as these practices grow in popularity. In addition, regulations on stormwater infiltration and capture are broad and overly restrictive for recharge use. Risk-based guidance should be developed to prevent overly restrictive policies which add unnecessary costs and barriers to stormwater infiltration and capture methods.

Evaluation and Demonstration of Stormwater Dry Wells and Cisterns in Millburn Township, New Jersey

Pitt, R., Telebi, L., Raghavan, R., Singer, M., Annoi, M., and T. Watkinson. 2012. PARS Environmental, Inc. Robbinsville, NJ 08691: 1-296.

Posted at: <http://nepis.epa.gov/Adobe/PDF/P100GLN2.pdf>

Purpose

The purpose of this study was to assess the water treatment ability and infiltration efficiency of dry wells in Millburn Township, New Jersey. Millburn was evaluating requirements for dry well use in new development.

Background

Millburn, a town located near New York City, has over 1500 commercial and residential dry wells. The town receives 44 inches of rain per year on average and has a water table that can be as shallow as 8 feet. New Jersey's dry wells are constructed following a set of regulations that include:

- a) Two foot separation between the dry well and the water table or bedrock.
- b) Maximum drainage area of 1 acre per dry well.
- c) Void volume of 250 cubic feet in dry well for every 1,000 square feet of impervious drainage area.
- d) Subsurface soil with highly permeable layers.
- e) Roof runoff as the only source.
- f) Construction of dry well must not compact subgrade soils.

Methods

Dry Well Design

The dry wells used in this study were open bottomed, concrete structures 6 feet in diameter and 6 feet deep with holes in the sidewalls. They rest on a 2 foot layer of crushed stone. Most received water from roof drain leaders or storm drain inlets in driveways or parking lots. Some also had grated covers and received surface runoff from surrounding lawns or paved areas. To facilitate collecting water for water quality analysis, three new dry wells were installed with underdrains, one right below each dry well and a second 2 feet below the gravel layer under the dry well.

Water Quality Measurements

Water samples were collected from the underdrains during or immediately after rain events for ten events for a year. The samples were tested for bacteria, nutrients, organics, metals, herbicides, and pesticides. Water samples were also collected from a cistern that received direct roof runoff and analyzed for the same set of contaminants.

Infiltration Efficiency Measurements

Different study sites had different characteristics that would likely influence infiltration rate. Most sites had low permeability surface soils and high permeability subsurface soils. The infiltration rate of dry wells was measured at 15 different sites over the course of a year.

Results/Discussion

Water Quality

There was little or no difference in water quality between the samples taken immediately below the dry wells and those collected 2 feet below the gravel layer under the dry wells. This indicated that the dry wells did not attenuate contaminants in the runoff. Bacterial and lead concentrations frequently exceeded drinking water criteria (MCLs). Bacterial levels were higher in samples collected from the lower underdrain and cistern than from the pipe directly below the dry well, although hold time for these water samples was exceeded so the results could underestimate growth. Organics such as chlordane, endosulfan-I, and heptachlor epoxide, were found in samples from the underdrains. In general, runoff from roofs was of higher quality than runoff from driveways and parking lots. This was the case for both stormwater and snowmelt.

Infiltration Efficiency

The site with permeable surface soil and subsurface soil had an infiltration rate of 7.6 inches/ hour, the highest among all dry wells. The sites with low permeability surface soils and high permeability subsurface soil had the second highest infiltration rate; 1.7 inches/hour. The difference between infiltration rates could be due to de-icing chemicals breaking up the clay surface soils, which released particles that clogged the dry wells. The site with low permeability surface and subsurface soils had an infiltration rate of only 0.8 inches/hour. This significant difference between infiltration rates is linked to either the low permeability of the subsurface soils and/or a water table.

Conclusion

The results of this study suggested that new dry wells did not attenuate contaminants in runoff during their first year in use. This indicates the need for pretreatment or for allowing only high quality runoff to enter the dry wells. Roof runoff was found to be of higher quality than stormwater generated from lawns/driveways for both rain and snowmelt, indicating that it would be the most suitable for dry well infiltration. The results also suggested that dry wells should not be used in areas where there is a high water table and/or low permeability subsurface soils.

Expanding local water supplies: Assessing the impacts of stormwater infiltration on groundwater quality

Dallman, S. and M. Spongberg. 2012. *The Prof. Geographer*. 64: 1 – 18. Posted at: <http://www.tandfonline.com/doi/pdf/10.1080/00330124.2011.600226>

Purpose

The Los Angeles Basin Water Augmentation Study (WAS) was performed to evaluate the practical potential to improve surface water quality and increase local groundwater supplies through infiltration of urban stormwater runoff. The initial phase of the study addressed the effects of stormwater on groundwater quality. The long term goal of the study was to identify advantages of infiltration practices and to determine an effective strategy for exploiting/expanding a potentially large source of water for Los Angeles. This article discusses the results of the WAS and provides further guidance to those investigating stormwater runoff as a potential water supply source. Multiple low impact development practices were examined in the WAS; this review will focus on the two sites that utilized drywells.

Background

Sixteen to 20% of the annual precipitation in the Los Angeles area infiltrates into the subsurface naturally, the remainder creates stormwater runoff. Capturing more stormwater runoff in unused local storage groundwater basins could substantially increase groundwater supplies. Public perception of stormwater reuse as a potential water supply is favorable, but this practice still faces regulatory hurdles.

Methods

Sites in this study that utilized dry wells included a residential and a commercial site. Groundwater levels were 9.75 meters below land surface (bls) at the commercial site and 60 + meters bls at the residential site. The dry wells were designed to accommodate a 19 mm/hour rainfall event at the commercial site and up to 51 mm/hour at the residential site. Structural treatments to remove sediment and oil/grease were installed at the residential but not the commercial site. Water quality was monitored in stormwater runoff, in the vadose zone, and at the water table.

Monitoring Program

Monitoring took place from 2001 to 2007, capturing results from one of the driest years to one of the wettest years on record. Stormwater was collected during storm events from roof surfaces and ground surfaces such as parking lots or driveways. Vadose zone samples were collected 2 –7 days after storm events using suction lysimeters 2 – 3 meters bls. Finally, groundwater samples were collected through monitoring wells in the fall prior to the first rain event and in late spring after the rainy season.

Analytical Chemistry

Contaminants analyzed included metals, oil and grease, organic and inorganic compounds, surfactants, and pathogens. Conventional water quality parameters were also measured. Trends were evaluated using the Mann-Kendall test.

Results/Discussion

Contaminants were detected at high levels in nearly all stormwater samples. In vadose zone and groundwater samples, contaminants were either not detected or detected at very low concentrations. The contaminants that were detected showed decreasing concentration trends throughout the course of the study. Volatile and semi-volatile organic compounds (VOCs and SVOCs) that were detected in the groundwater were different contaminants than those detected in the stormwater. Additionally, the organic contaminants detected in the groundwater were also detected in groundwater samples collected upgradient of the dry wells. This suggests that VOCs and SVOCs in stormwater did not contribute to organic contaminant concentrations in the groundwater.

Inorganic constituents such as nitrate, total dissolved solids (TDS), and chloride tended to be lower in stormwater runoff than concentrations in lysimeter and groundwater samples. For example, TDS in stormwater ranged from 6.7 to 37 mg/L but ranged from 500 and 900 mg/L in groundwater tested at the commercial site. Concentrations of metals in stormwater were variable but in general were stable or decreasing over time at both sites.

Conclusion

Overall, the data collected during six years of monitoring showed little evidence that stormwater infiltration had a negative impact on groundwater. In addition, the presence of organic compounds in the upgradient groundwater samples suggested that contamination of groundwater has already occurred from other sources. Concentrations of most constituents tend to be lowest in the surface runoff. In many cases, stormwater infiltration through dry wells actually diluted the concentrations of contaminants already present in groundwater. No buildup of contaminant concentrations in the soil was evident, suggesting contaminants introduced into the soil from stormwater infiltration do not migrate to the groundwater. This study suggests that pollutants of environmental concern in runoff are intercepted during the process of infiltration and effectively prevented from reaching groundwater aquifers. Stormwater capture reduces pollutant discharges into surface waters and lowers demands on the flood control system. Stormwater management that treats runoff as a valuable resource is gaining favor. Using urban runoff to recharge groundwater is a practical option for expanding local water supplies.

Potential effects of roadside dry wells on groundwater quality on the Island of Hawai'i – Assessment using numerical groundwater models

Izuka, S.K. 2011. U.S.G.S. Scientific Investigations Report 2011-5072, pp. 1 – 30. Posted at:

<http://pubs.usgs.gov/sir/2011/5072/sir2011-5072.pdf>

Purpose

The purpose of this study was to generate 3-D groundwater models that could be applied to the entire Island of Hawaii to assess the potential effect dry wells have on groundwater quality. The study focused on the effects of contaminants entering dry wells and groundwater with different hydrogeological conditions, such as climate, hydraulic conductivity, aquifer properties, and regional groundwater gradient.

Background

Geologically, the island consists of high porosity rock layers formed by lava flows. Groundwater reaches near sea level along the coast and rises in elevation by a few feet per mile moving inland creating a dome-like shape. Much of the island's land surface is bare rock. Rainfall in the northeastern area of the island can exceed 260 inches per year, while precipitation on the western coast is relatively low. Stormwater runoff entering dry wells may contain sediment and contaminants such as metals, oil and grease, fuel, pesticides, organic compounds, nutrients, and microorganisms. More than 2,000 dry wells have been installed on the Island of Hawaii to dispose of stormwater runoff from roads.

Methods

Models able to simulate groundwater flow and solute transport were generated using a computer program (SEAWAT). In order to meet the goal of island-wide applicability for this study, variables in the models were generalized to represent the range of hydrogeological conditions on the Island of Hawaii. The models simulated a single, hypothetical, non-reactive contaminant, with recharge being the sole source. It was assumed that the "contaminant" was transported through the vadose (unsaturated) zone by advection¹ only. The hypothetical contaminant was also assumed to have the same density as freshwater, eliminating density-dependent flow simulations.

To facilitate comparisons between different conditions, a pulse of water flowing at 5 cfs for one hour was used for dry well inflow in all model simulations. Simulated flows were equivalent to the design capacity of dry wells used on the Island of Hawaii.

Results/Discussion

Eleven models were generated based on information extracted from existing dry wells in Hawaii. The models showed that contaminant concentration was dependent on vadose zone thickness, vertical distance from the infiltration area, the infiltration rate, and hydraulic properties; such as conductivity and pressure head.

Overall, results showed contaminant concentrations in groundwater were inversely related to vadose zone thicknesses. Contaminant concentrations decreased with distance from the dry well or natural

¹ Advection refers to the movement of a pollutant as part of a plume of water.

infiltrating area in all directions. Contaminant concentrations in the plume were attenuated by advection and hydrodynamic dispersion² as they traveled with the regional groundwater flow. The results of the study indicated that mixing contaminated water with contaminant-free water in the aquifer immediately reduced the contaminant concentration. Simulated contaminant concentrations directly beneath a dry well were nearly 8 times higher than directly beneath a broad infiltration area representing the natural condition. Gradual recharge and lower vertical hydraulic conductivity resulted in reduced contaminant concentrations in the aquifer. Estimates of contamination risk are highly conservative because the models simulated a non-reactive, non-decaying contaminant.

Conclusion

The extent of contaminant concentration in groundwater below dry wells depends on multiple variables. Results from the models were used to assess how contaminants entering a dry well may affect groundwater in a variety of situations on the Island of Hawaii. The necessary generalizations that made the results applicable island-wide also limited the precision of the assessment. The findings showed that models could be adapted to other localities if site-specific data was available. Determining if a dry well increased or decreased the potential for groundwater contamination of the aquifer relied on site-specific conditions that a single generalized model could not predict. A better assessment would be achieved by using a model with hydrogeological conditions specific to the dry well in question.

OEHHA Note: The model used in this study can be applied to California. The input values for the variables would need to be changed to represent the specific location of the dry wells in California.

² Hydrodynamic dispersion refers to how much contaminants spread (in all directions) away from the mean path of the groundwater.

The Los Angeles and San Gabriel Rivers Water Augmentation Study

The Los Angeles and San Gabriel Rivers Watershed Council.

2005. **Phase II Final Report.**

2008. **Phase II Monitoring Report Update**

2010. **Ground Water Augmentation Model Demonstration Report.**

Posted at: <http://watershedhealth.org/programsandprojects/was.aspx>

Purpose

The purpose of this study was two-fold: to assess the potential of stormwater infiltration practices, including dry wells, to contaminate groundwater and to assess the volume of water that could be collected to recharge the aquifer, providing drinking water for residents of the region.

Background

On average, over 500,000 acre-feet of runoff flow to the ocean from Los Angeles County each year. If a portion of this water could be used to recharge groundwater, the demand for water from northern and central California could be reduced. The depth of the water table in Los Angeles varies greatly, ranging from 20 feet to greater than 350 feet below land surface (bls). The soil types span the full permeability range of hydrologic soil groups (HSG) A-D.

Methods

The study was conducted throughout Los Angeles at sites with various land uses including two industrial sites, an elementary school, a commercial office building, a private residence, and a public park. The sites were retrofitted with infiltration practices such as dry wells, vegetated swales, detention basins, sand/oil interceptors, catch basins, and large-scale underground infiltration galleries. Stormwater, vadose zone, and groundwater sampling was conducted from 2001 to 2005. Stormwater samples were collected as time-weighted composites every 30 minutes during the first two hours of storm runoff. Vadose zone samples were taken 2 – 7 days after storm events using lysimeters installed beneath the ground surface. Groundwater samples were taken from monitoring wells before and after the rainy season as well as 2 –7 days after storm events during the water year. The samples were analyzed for approximately 80 contaminants including minerals, metals, oil and grease, perchlorate, pesticides, volatile and semi-volatile organic compounds, surfactants, and bacteria. The study was performed during a period when organophosphates (OP) were widely used; samples were not analyzed for pyrethroids. Vadose zone and groundwater sampling was extended for two years after the initial 5-year study; until 2007 at some sites. These samples were analyzed for metals, perchlorate, volatile organics, and general parameters such as conductivity and pH. Fuel oxygenates and methyl tert-butyl ether were also included in the list of analytes.

Study Sites

Only two of the study sites incorporated dry wells as infiltration features:

IMAX Corporation Site

IMAX Corporation is a 3.5 acre commercial site where a shallow dry well was installed that collected roof runoff and a vegetated area that received parking lot runoff. At this site, stormwater sampling was conducted between 2001 and 2005 while groundwater and vadose zone sampling was conducted between 2001 and 2007. Stormwater samples were collected from the front of the parking lot as it drained into the vegetated area and from the roof downspout. Vadose zone water samples were collected with an 8 foot deep lysimeter adjacent to the dry well. Groundwater samples were taken from upgradient and downgradient monitoring wells. Infiltration rates after storm events were determined using soil moisture sensors installed at depths 2, 5, 10, and 20 feet. Groundwater depth at this site was 32 feet bls.

Hall House Site

Hall House is a residential site that was retrofitted with a shallow dry well that received runoff from a trench drain in the driveway and a swale that collected runoff from the roof. At this site, stormwater and vadose zone sampling was conducted between 2001 and 2005. Stormwater samples were collected from the roof drain and the driveway. Vadose zone samples were collected with a lysimeter near the roof drain. Monitoring wells were not installed at this site because local groundwater depth was greater than 200 feet bls. Boring logs showed that the upper 6 feet of sediment consisted of silt with minor amounts of sands and clay.

Recharge in Los Angeles Region

The Ground Water Augmentation Model (GWAM) was developed for use in the Los Angeles region. GWAM is based on two principles:

- 1) Infiltration = Precipitation – (Evaporation + Runoff)
- 2) Deep Percolation = (Antecedent Soil Moisture + Infiltration + Irrigation) – Evapotranspiration

The model used runoff-diversion-to-infiltration scenarios to estimate the potential increase in groundwater recharge upon the installation of best management practices (BMPs) such as dry wells.

Results/Discussion

Results suggested that stormwater infiltration through dry wells did not degrade groundwater quality. The concentrations of most pollutants in runoff, vadose zone, and groundwater samples were below Maximum Contaminant Levels (MCLs) and Public Health Goals (PHGs). Pollutant concentrations were generally lower in runoff samples from rooftops than from the ground surface. Concentrations of metals tended to be higher in stormwater than in subsurface water samples. Volatile organic compounds (VOCs) detected in groundwater were different contaminants than those detected in stormwater, indicating that VOCs in stormwater did not impact groundwater. Polycyclic aromatic hydrocarbons (PAHs) were not detected in any sample during the course of this study. There were a few instances where the concentrations of contaminants in groundwater exceeded the relevant PHGs; however, they appeared to reflect pre-existing conditions and were not statistically linked to stormwater infiltration.

At the IMAX dry well site, total and dissolved arsenic were the only pollutants to exceed PHGs in any sample (Table 1). Specific conductance in the groundwater was approximately 1000 micromhos/cm ($\mu\text{mhos/cm}$) in both upgradient and downgradient monitoring wells. This high specific conductance may have influenced in the elevated concentrations of arsenic in the groundwater. All other pollutants were below MCLs and PHGs in stormwater, vadose zone, and groundwater samples. Additionally, most pollutant concentrations showed either decreasing or variable trends in the vadose zone and groundwater throughout the study. This suggested that over time it will be unlikely that pollutant concentrations will build up in the vadose zone or groundwater. Only chemical oxygen demand showed a statistically significant increasing trend in the vadose zone.

Table 1. Pollutants exceeding MCLs and/or health-based advisory levels in stormwater, vadose zone, or groundwater at the IMAX dry well site. Values represent the range and sample size in parentheses. ND = non-detect. ^p = PHG

Contaminant	Stormwater ($\mu\text{g/L}$)	Vadose Zone ($\mu\text{g/L}$)	Groundwater ($\mu\text{g/L}$)	MCL ($\mu\text{g/L}$)	Health-based advisory level ($\mu\text{g/L}$)
Total Arsenic	ND-6.51 (8)	1.51-8.48 (9)	ND (9)	10	.004 ^p
Dissolved Arsenic	ND (8)	1.62-6.78 (6)	ND-1.67 (9)	10	.004 ^p

Pollutant concentration in groundwater did not reflect those in stormwater at the IMAX site. Pollutants with high concentrations in stormwater had low concentrations in groundwater while pollutants with high concentrations in groundwater had low concentrations in stormwater. This suggested that stormwater infiltration through the dry well had not contributed to groundwater contamination but that external sources accounted for the presence of groundwater contaminants.

At the Hall House dry well site, total and dissolved arsenic concentrations were the only contaminants to exceed PHGs (Table 2). All pollutant concentrations in the vadose zone showed either variable or statistically significant negative trends during the study period. This suggested that contaminants are unlikely to build up in the vadose zone over time as a result of stormwater infiltration through the dry well. Nitrate, TDS, and chloride were higher in vadose zone water samples than those found in stormwater samples. However, it does not appear that stormwater infiltration could be responsible for their presence because their concentration in the vadose zone declined over the course of the study. The concentrations of metals in stormwater varied, but were generally lower than those found in vadose zone samples. The exception to this was arsenic. Perchlorate was not detected in stormwater samples and therefore, was not analyzed in vadose zone samples.

Table 2. Pollutants exceeding MCLs and/or health-based advisory levels in stormwater or vadose zone at the Hall House dry well site. Values represent the range and sample size in parentheses. ND = non-detect. Groundwater samples were not collected at the Hall House. ^p=PHG

Contaminant	Stormwater (µg/L)	Vadose Zone (µg/L)	MCL (µg/L)	Health Based Advisory Level (µg/L)
Total Arsenic	ND (4)	ND (5)	10	.004 ^p
Dissolved Arsenic	ND (3)	ND-4.26 (6)	10	.004 ^p

Recharge Capacity through Stormwater Infiltration

The GWAM estimated that 16% (194,000 acre-feet) of precipitation percolates past the root zone as recharge while 48% (600,000 acre-feet) of precipitation becomes runoff which flows into storm systems, rivers, and the ocean. The data indicated that if infiltration practices were widely developed in the Los Angeles region, it would result in a 384,000 acre-feet/year increase in groundwater recharge; enough to supply water for three-quarters of a million typical Southern California families for a year.

Conclusion

The various infiltration practices examined in this study did not appear to contribute to groundwater contamination during the six-year period of the study. The use of a dry well with no pretreatment at a commercial site with a relatively high water table (IMAX) did not contribute to vadose zone or groundwater contamination. Additionally, the use of a dry well at a residential site (Hall House) did not contribute to vadose zone contamination. All pollutant concentrations in groundwater at IMAX showed variable or statistically significant negative trends, suggesting that pollutant concentrations will not build up in the groundwater over time. Furthermore, most pollutant concentrations in the vadose zone at both IMAX and Hall House showed variable or statistically significant negative trends. This indicates that pollutant concentrations will likely not build up in the vadose zone over time. The results of this study also suggested that if infiltration practices were widely developed in the Los Angeles region, it would result in a 384,000 acre-feet/year increase in groundwater recharge, enough to supply 750,000 Southern California families for a year.

PUBLISHED BETWEEN 2000 - 2010

Decision Making Framework for Groundwater Protectiveness Demonstrations: Underground Injection Control System Evaluation and Response

City of Portland Bureau of Environmental Services. 2008.

Posted at: <http://www.portlandoregon.gov/bes/48213>

Purpose

The goal of this study was to create a framework and modeling tool to be used to protect groundwater (GW) quality in areas of Portland, OR where Underground Injection Control systems (UICs) are used to infiltrate stormwater. The City of Portland's goals for their UIC project were to utilize stormwater to enhance aquifer recharge in urban areas and to protect groundwater as a drinking water resource while at the same time reduce the harmful effects of runoff on the aquatic ecosystem. Additionally, Portland wanted to identify actions that removed pollutants before they entered the dry wells. The tool and framework were intended to evaluate the stormwater runoff monitoring results, determine necessary vertical separation distances between the bottom perforation of the UIC and the water table, identify areas that need further attention, define generic conditions for which groundwater is protected, determine if groundwater meets well and drinking water standards, and evaluate or address regional UIC issues.

Background

Regulations

Portland's UIC program operates under Federal, State, and City regulations. Federal regulations state that UICs must be authorized under a rule or permit designed to prevent contaminated fluid exceeding the Safe Drinking Water Act's established MCLs (Maximum Contaminant Levels) from entering a drinking water source. Oregon's Department of Environmental Quality (DEQ) requires that groundwater quality in areas with UICs must be maintained at the natural background levels. For areas with drinking water wells, the federal MCLs must be met. Oregon's Groundwater Protection Act requires a permit to discharge into "waters of the state".

The City established a permit system by which UICs may only be installed and operated if they meet the requirements of the DEQ issued permit. Portland's Stormwater Manual stipulates design criteria for UICs. The permit requires that stormwater meets federal MCLs at the point at which it enters the top of the UIC. The Portland UIC program refers to these standards as Maximum Allowable Discharge Levels or MADLs. Further, affected GW must meet Oregon GW protection standards. The permit mandates ten years of monitoring to verify the safety of drinking water.

UICs in Portland

There were 9,000 publically-owned and 10,000 privately-owned UICs in Portland at the time of the study. The majority of the wells were in eastern Portland, where soils generally have higher infiltration capacities. In some areas east of the Willamette River, UICs are the only available form of stormwater disposal. A typical City-owned UIC system consists of a catch basin, a sedimentation manhole, and the

actual dry well (Figure 1). The catch basin, or other form of stormwater inlet, captures stormwater and discharges it into a sedimentation manhole, a solid concrete cylinder generally 10 feet deep and 4 feet

wide. A “bent elbow” drainpipe connects the sedimentation manhole and the UIC, and particulates and floatables (e.g. oil, debris) are retained in the manhole prior to being discharged into the dry well. The UICs themselves are generally 4 feet in diameter and range in depth from 2 - 40 feet, with the majority being 30 feet deep.

Environmental Setting

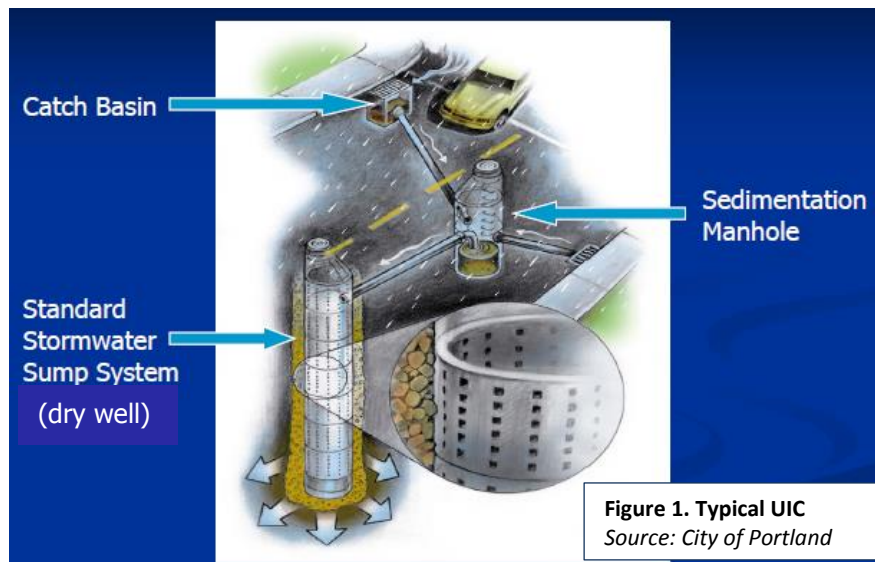
Most of Portland lies within the Portland Basin, bounded to the west by the Portland Hills, and to the east by the Cascades. The Portland Basin is 20 by 45 miles in area and filled with up to 1,600 feet of sedimentary deposits. Portland UICs tend to be located in either late Pleistocene flood deposits (both coarse and fine grained) or the Pleistocene upper Troutdale Formation, which is cemented gravel (material ranging in size from pebbles to boulders) mixed with a sand and silt matrix. The water table depth in the region ranges from approximately 200 feet in eastern Portland to less than 2 feet near the Columbia River. The area’s GW is aerobic with near neutral pH. The region’s gravel and sands contain low concentration of organic carbon.

Study Design

Monitoring

The permit granted by DEQ required that stormwater monitoring occur for 10 years after the start of the study. Thirty wells were randomly chosen through statistical analysis to be monitored during Year 1. Of these, 15 were rotating locations sampled for 5 storm events per year, and the remainder were fixed locations also sampled for 5 storm events during the wet season of the water year. Water samples were taken from the point where stormwater enters the top of the sedimentation manhole, and were analyzed for common pollutants, such as metals, volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), polycyclic aromatic hydrocarbons (PAHs), pesticides, and Priority Pollutant Screen (PPS), composed of a list of common contaminants which includes benzene, pentachlorophenol (PCP), chromium, toluene, xylenes, phthalates, arsenic, copper, and nitrogen.

Forty-one UICs were sampled during Year 2. Once again, 15 rotating locations and 15 fixed locations were monitored as well as 1 UIC that had not met Permit compliance in Year 1, and 10 UICs located near drinking water wells. Five sampling events were again completed. Year 2 monitoring well samples were tested for common pollutants. This study contains data from these two years.



Pollutant Selection

Monitoring results were used to identify the pollutants that would be used in the fate and transport analyses. Pollutants were selected to represent six broad chemical categories: VOCs, SVOCs, PAHs, pesticides/herbicides, metals, and miscellaneous pollutants (such as nitrates). Pollutants were chosen based on their frequency of detection in Year 1 and 2 monitoring results, their mobility, persistence, and toxicity to humans.

Groundwater Protection Demonstration Tool

The Groundwater Protection Demonstration (GWPD) tool is a solute transport spreadsheet model developed in two phases. In Phase 1, the methodology and assumptions necessary to evaluate PCP exceedance of the MADL were analyzed. Phase 2 continued development of the model by evaluating MADL exceedance of multiple pollutants while also assessing the minimum vertical separation distance between the bottom of the UIC and the water table. The last phase of work involved using the results obtained with the GWPD tool to develop a generic GWPD Framework to apply to broader UIC issues.

The GWPD Tool is based on a 1-D solute transport equation that predicts how much a pollutant's concentration in stormwater will decrease as stormwater flows out of the UIC and through unsaturated soil (vadose zone) before it reaches groundwater. Physical, chemical, and biological characteristics of both the pollutants and the unsaturated soil were used as input parameters. Porewater velocity, porosity, soil moisture content, the fraction of organic carbon, organic carbon partitioning coefficient, hydraulic conductivity, and degradation rate were determined using literature values for the area.

Results/Discussion

Monitoring

During Year 1, thirteen out of 14 common pollutants were detected in stormwater. Seven out of 27 PPS analytes were detected, and 35 common pollutants were detected at low concentrations and frequencies. Three of the common pollutants were detected above the MADL during individual sampling events: Pentachlorophenol (PCP) at 9 locations, di(2-ethylhexyl)phthalate (DEHP) at 4 locations, and lead at 3 locations. PCP's geometric mean also exceeded its MADL at 5 locations. PAHs were detected most frequently; naphthalene had the highest concentration.

During Year 2 all of the common pollutants, two PPS analytes (2,4-D and chlorobenzene), and 26 ancillary pollutants were detected (of which naphthalene again had the highest concentration). PCP, DEHP, and lead again exceeded their MADLs during individual sampling events, and PCP's geometric mean concentration exceeded its MADL at 9 locations.

Pollutant Selection

The following pollutants were selected for model analysis. Toluene was selected to represent VOCs; PCP and DEHP to represent SVOCs; benzo[a]pyrene and naphthalene for PAHs; 2,4-D and methoxychlor for pesticides and herbicides; and copper and lead to represent metals. Representatives from the miscellaneous pollutants category were not selected, as this category was not found to be a concern. Some pollutants were chosen because they posed more of a threat to water quality than other detected pollutants in the same category, such as toluene for benzene and xylenes.

Groundwater Protection Demonstration Tool

Fate and Transport Analysis

Scenarios depicting average and worst-case conditions were created and models were run for both 5 and 7 foot separation distances through each of the chosen representative soil facies: coarse and fine-grained flood deposits, and the upper Troutdale formation. The model's results show that even with a 5 foot separation distance and travelling through the most permeable geologic material, all of the selected non-metal pollutants are reduced by more than 99% before they reach the water table. It was estimated that it would take copper and lead 1,600 and 2,150 years respectively to reach the water table, and when they did their concentrations would be below the MCL (MADL).

Separation Distance Analysis

Oregon law stated at the time that UICs must have a vertical separation distance of a minimum of 5 feet. Less than 2% of the City's UICs were non-compliant with this law. Less than 4% of the UICs had separation distances less than 10 feet, and 94% of the UICs had separation distances of or greater than 10 feet, ranging from 10 to more than 148 feet. The results of the model showed that a 5 foot separation distance was protective of GW, even when all of the pollutants have an input of 10 fold greater than the MADLs under typical conditions. Five feet of separation was also found to be protective against bacteria.

Conclusions

This study reports the findings of the first two years of a ten year project. After two years of monitoring and with ten storm event samplings total, it was determined that only benzo[a]pyrene, PCP, and lead exceeded their MADL requirements at the point where stormwater enters the UIC and only at a handful of UICs. Modeling suggested that all chosen monitored pollutants were adequately reduced by infiltration through subsurface soils before reaching the water table. Stormwater discharges met the intent of Oregon's GW quality protection rules. The study showed that stormwater discharged into the vadose zone can be environmentally beneficial as a source of aquifer recharge and stormwater management, with an adequate separation distance (at least 5 feet). The results of monitoring Years three through ten has been reviewed in more recent publications, which can be viewed on the Portland UIC program website (<http://www.portlandoregon.gov/bes/48213>).

Hydrogeology, water chemistry, and factors affecting the transport of contaminants in the zone of contribution of a public supply well in Modesto, eastern San Joaquin Valley, California

Jurgens, B.C., Burow, K.R., Dalgish, B.A., and J.L. Shelton. 2008. USGS Scientific Investigations Report 2008-5156. 78 p.

Posted at: <http://pubs.usgs.gov/sir/2008/5156>

Purpose

The U.S. Geological Survey conducted a large nationwide survey of drinking water quality in six cities throughout the nation. One of the cities they selected was Modesto, CA. Although not the purpose of the study, due to the fact that dry wells have been used in the City since the 1950s, this study can shed light on the potential long term effects of infiltrating stormwater through dry wells on groundwater (GW) quality.

Study Design

Study Area Description

Modesto has subsurface geology that is comprised of interlayer lenses of gravel, sand, silt, and clay. The aquifer in the study area is primarily unconfined in the shallow part of the system and becomes semi-confined with depth due to numerous overlapping, discontinuous clay lenses. Contaminants in GW can move downward relatively freely in an unconfined aquifer compared to one that is confined or constricted by clay. Groundwater hydrology has been altered by urban and agricultural activities through a system of wells that withdraw and recharge water. Dry wells account for much of the GW recharge from urban irrigation and storm events, while GW withdrawals are the result of agricultural pumping and pumping for drinking water. The cycle of water withdrawals and recharge has caused the water in the upper aquifer to be drawn downward to deeper aquifers.

Monitoring Well

A network of 23 monitoring wells (MW) was constructed in the vicinity of a public drinking water supply well. The MWs were completed at depths ranging from 16 feet below land surface (bls) to more than 300 feet in order to sample groundwater from the perched aquifer (28 - 38 feet bls) as well as the shallow (95 - 115 feet bls), intermediate (166 - 215 feet bls), and deep (328 - 347 feet bls) aquifers. To identify constituents entering the dry wells, urban runoff samples were collected near two dry wells once during the winter and again in the summer. All water samples were collected and analyzed for conventional water quality parameters (e.g. pH, dissolved oxygen), inorganic constituents (e.g. metals), pesticides (e.g. simazine, chlorinated pesticides and herbicides), and volatile organic compounds (VOCs). VOCs analyzed included contaminants related to paints, solvents, refrigerants, fumigants, and gasoline (BTEX; benzene, toluene, ethylbenzene, and xylenes), and isotopes such as uranium. Standard quality control blanks, spikes, and replicates were analyzed along with water samples. Water age was also determined using isotopic analysis. The age of GW was used to characterize the flow paths of GW and the susceptibility of aquifers at different depths to contamination.

Results/Discussion

Age of Groundwater

Results of sampling GW with age tracers showed that the water quality and age of the aquifer is stratified into shallow, intermediate, and deep zones. The age of the water varied from less than 50 years old in the shallow zone to thousands of years in the deep zone. Water at the water table and shallow zones contained higher concentrations of nitrate, dissolved salts, sulfate, uranium, VOCs, and pesticides than samples collected from the intermediate and deep zones. Water in the deep zone of the aquifer contained no anthropogenic contaminants but had concentrations of nitrate, uranium, and alkalinity that were consistent with recharge under natural conditions. The intermediate zone was a mixture of newer water subject to human influences and older, cleaner water.

Conventional Water Quality Parameters

Water chemistry was vertically stratified depending on the depth of the water. Specific conductance, a measure of total dissolved ions, was highest near the perched water table, with a median value of 886 micromhos/cm ($\mu\text{mhos/cm}$), and fell to a median value of 201 $\mu\text{mhos/cm}$ in the deep aquifer. Similarly, pH ranged from 6.8 near the land surface to 8.1 in the deep aquifer. Dissolved ion concentrations, were strongly correlated with alkalinity measurements (primarily bicarbonate). This suggests that salts commonly associated with urban runoff influenced the shallower aquifers. All groundwater samples had an oxygen-reducing environment.

Pesticide and Volatile Organic Compounds in Groundwater

Ten pesticides were detected in 23 GW samples from the monitoring wells. The most frequently detected pesticides were atrazine degradation products and simazine, both widely used agricultural chemicals. The shallower GW wells (less than 100 feet below level surface or bls) had higher concentrations of pesticides than the deeper wells. About two-thirds of all pesticide detections were found in monitoring wells less than 40 feet deep, suggesting that human activities directly affected the chemistry of the water recharging the shallow aquifer. Many of the detections were attributed to agricultural land uses. None of the groundwater samples had pesticide concentrations above the Maximum Contaminant Level (MCL), the regulatory drinking water standard. In most cases, pesticide concentrations were 100 times below the MCL.

Volatiles were also widely detected in shallower wells, chloroform being the most frequently detected compound. Chloroform, a disinfection by-product, was associated with leaking water distribution lines and/or residential irrigation. Solvents were widely detected; tetrachloroethylene (PCE) being the most commonly detected solvent localized in shallows wells. PCE was detected in two GW wells at concentrations just below the MCL, while in most wells its concentration was generally 100 fold lower than the MCL. Lastly, gasoline-related compounds were found in some shallow wells, however none were found in the deep aquifer.

Pesticides and Volatile Organic Compounds in Stormwater

Nine pesticides and four VOCs, mostly gasoline-related compounds, were detected in stormwater (SW) runoff samples. Two of these 9 pesticides, DCPA (dimethyl tetrachloroterephthalate), and

pendimethalin, were detected in GW samples; however, none of these concentrations, including those of VOCs, exceeded regulatory standards.

Nitrate

Nitrate was detected in all groundwater samples, with a median concentration of 4.0 mg/L. Six monitoring wells (including all 3 shallow wells) exceeded the MCL for nitrates (10 mg/L). These wells were located at sites with current or recent agricultural use. Nitrate concentrations in drinking water however, did not exceed the MCL. This was the case because the water delivered via the public supply wells is a mixture of water drawn from various depths, diluting the higher concentrations of some contaminants in the shallower aquifer. The data showed nitrates generally decrease with aquifer depth. Isotopic analysis of nitrate in groundwater samples suggested its sources were inorganic fertilizers, soil nitrogen, and septic waste. However, urban recharge has lower concentration of nitrate, thus could reduce groundwater concentrations of nitrate over time.

Arsenic

Arsenic, a naturally occurring trace element, was detected in all GW samples at concentrations between 2.3 – 15.9 µg/L. One shallow and two water-table GW wells exceeded arsenic's MCL (10 µg/L) although drinking water collected from the public supply well did not exceed the MCL. The concentration of dissolved arsenic in groundwater has been shown in other studies to be controlled by a variety of processes that can inhibit its adsorption to vadose zone and aquifer sediments, including elevated pH (pH > 8.0), an environment that causes reduction of other metals such as iron which often bind arsenic, and alkalinity. In this study, dissolved arsenic was not correlated with pH. Anions, such as orthophosphate, could also inhibit the adsorption of arsenic to sediments. Other complex interactions of arsenic with ions were discussed in the report. Arsenic concentrations in groundwater were not related to land use, however, infiltration of water that alters the redox condition could affect solubility of arsenic.

Uranium

Uranium (U), another naturally occurring metal, is a minor constituent of granitic rock. Uranium exceeded the MCL (30 µg/L) in two GW wells. Uranium was not adsorbed by sediment in shallower portions of the aquifer (< 50 feet bls) but at greater depths, U was remained bound to sediment. This suggests that geochemical conditions in shallow aquifers such as more oxygen-rich water, favor the release of U from particles. While similar concentrations of uranium were found in agricultural and urban areas, these elevated levels of U are likely associated with high concentrations of bicarbonate, alkalinity, sulfate, and other major ions linked to stormwater and agricultural runoff. The high levels of specific conductance associated with these salts caused the release of uranium from rocks/sediments, after which it became mobile in the groundwater.

All other water samples, including those from the public supply well, met water quality standards.

Conclusions

The hydrology, water chemistry, and other factors affecting drinking water quality were investigated in Modesto, CA. No urban contaminants collected from groundwater monitoring wells exceeded the MCL.

VOCs generally were detected beneath urban land while pesticides were present beneath agricultural and urban land uses. The only contaminants in the aquifer with concentrations exceeding their MCLs were uranium and nitrate. Uranium was associated with the geology of the region, while nitrate was linked with agricultural practices. They were found in high concentrations in shallow monitoring wells, and similar to other contaminants, their concentrations decreased with depth. Continued downward migration of oxygenated, high-alkalinity groundwater from shallower depths, most influenced by recharge, could mobilize the available fraction of uranium from deeper sediments. On the other hand, increased urban recharge which has lower nitrate concentrations could decrease the nitrate concentrations in deeper aquifers and reduce quantities in drinking water.

Groundwater chemistry at the shallow and intermediate depths of the aquifer was influenced by both agricultural and urban activities. However, because the amount of recharge from agriculture is greater than urban, the chemistry of the GW up to about 100 feet bls, where water can be up to 40 years old, is likely influenced more by agricultural practices than urban. At intermediate depths (165 – 215 feet bls) of groundwater, the water quality was higher than what was found in shallower zones of the aquifer. Because much of the land was farmed prior to urbanization, intermediate-depth GW was more affected by agricultural practices than urban land uses. Deep GW (up to 350 feet bls) has been unaffected by land use practices, reflecting GW that evolved under natural conditions.

OEHHA Note: Dry wells are Modesto's main method of stormwater runoff management, having been used for over 50 years. Aquifer recharge influenced the shallow zone of the aquifer, and to a lesser extent the intermediate zone. Key organic and metal contaminants examined in these aquifer zones were associated with agriculture, not urban, land use. However, elevated alkalinity, a product of both agricultural and urban irrigation practices, increased desorption of uranium from aquifer sediment. Arsenic was mobilized under high pH conditions (> pH 8.0) and the presence of various cations and anions. This suggests that urban stormwater, primarily infiltrated through dry wells, has the potential to indirectly affect the concentration of dissolved elements, such as uranium or arsenic, in the aquifer.

Influencing factors and a proposed evaluation methodology for predicting groundwater contamination potential from stormwater infiltration activities

Clark, S.E. and R. Pitt. 2007. Water Environ. Res. 79(1): 29 – 36.

Posted at:

http://www.redorbit.com/news/science/825701/influencing_factors_and_a_proposed_evaluation_methodology_for_predicting_groundwater/

Purpose

The purpose of this paper was to develop a method for evaluating the potential for groundwater contamination associated with stormwater infiltration.

Background

Infiltration practices are widely used to reduce the harmful effects of stormwater runoff on the aquatic ecosystem and to increase groundwater recharge. However, there are concerns that stormwater infiltration has the potential to contaminate groundwater.

Methods/Results/Discussion

The following three steps were suggested to aid in selecting a design for stormwater infiltration systems:

1. Determine the chemical forms and concentrations of pollutants in stormwater. The design should also consider whether or not the pollutant is associated with particulates, dissolved ions, or colloids. Pollutants of concern included nutrients, pesticides, organics, pathogens, metals, salts, and sediment.
2. Determine the characteristics of the soil to determine if it has the potential to adsorb/degrade contaminants. Soil characteristics that affect contaminant transport and infiltration rates include texture, intrinsic permeability, hydraulic conductivity, pH, organic content, and cation exchange capacity. Additionally, the presence of microorganisms and pore space volume can influence degradation of contaminants and transport through the vadose zone.
3. Determine the stormwater pretreatment requirements to minimize groundwater contamination. Pretreatment can detain particulates which carry pollutants.

Two types of models were used to evaluate the potential for groundwater contamination and to aid in selecting a suitable infiltration system:

1. A simplified chart that ranked and linked the mobility of pollutant classes to concentration levels.
2. A vadose zone model that estimated the movement of pollutants in the soil and predicted concentrations that might accumulate in the groundwater at various depths.

In a case study, both models were used to evaluate the best infiltration method for an industrial site's galvanized roof runoff. The simplified model analyzed the mobility and contamination potential of zinc and anticipated the likelihood that it would react with the soil and be removed before reaching the

groundwater. In contrast to the results obtained with the chart, the computer model used local input data to show that the soil would not provide sufficient pollutant removal. It should be noted that neither model considered runoff pretreatment methods.

Conclusion

Selection of the appropriate infiltration device should be determined by evaluating pollutants of concern in the stormwater and determining soil characteristics that affect pollutant migration. After those determinations are made, model predictions can be used to select the most suitable infiltration method. The authors noted that surface percolating devices were preferred over the use of dry wells to prevent groundwater contamination at the location of the case study. The authors recommended that a pretreatment be used to minimize the likelihood of groundwater contamination and clogging of the dry well.

PUBLISHED BETWEEN 1990 - 2000

Groundwater contamination potential from stormwater infiltration practices

Pitt, R., Clark, S. and R. Field. 1999. Urban Water 1(3): 217 – 236.

Posted at:

http://www.researchgate.net/publication/222468641_Groundwater_contamination_potential_from_stormwater_infiltration_practices/file/60b7d523c9e3b35d0a.pdf.

Purpose

This paper reviewed scientific studies on the common stormwater contaminants and the potential of stormwater infiltration practices to introduce these contaminants into the aquifer.

Background

In many regions of the United States, expanding urbanization has resulted in an increase of pollutants in stormwater runoff. At the same time, infiltration practices such as rain gardens and dry wells are being used more frequently to manage stormwater runoff. There is concern that the runoff that passes through these systems has contaminated or could contaminate groundwater.

Results/Discussion

Common stormwater pollutants that have the potential to contaminate groundwater include nutrients, pesticides, organics, pathogens, metals, and salts, as discussed in the following sections:

Nutrients in the Form of Nitrate:

Nitrate has been found at high concentrations in groundwater in regions that are heavily populated or have high dairy, poultry, and agricultural activity. Sources of nitrate contamination include roadway runoff, irrigated agriculture, and leakage from sanitary sewers/septic tanks. Unlike many other contaminants that are hydrophobic and adsorbed onto particles, nitrate is highly soluble, mobile, and therefore poses a risk to groundwater quality.

Pesticides

The amount of pesticides in runoff has been correlated with the amount of impervious cover and the distance the runoff has to travel prior to infiltration or decomposition. A number of pesticides, including diazinon, dacthal, and dioxathion, were detected in runoff entering urban dry wells in Arizona while diazinon and methyl parathion were found in groundwater below wastewater treatment plants in Florida. Diazinon was also reported in stormwater recharge basins in Fresno, California. Pesticides are mobile in coarse-grained or sandy soils when their pH is similar to that of the soil. When structural voids in the soil exist, adsorbing soil matrices are bypassed, allowing pesticides to move down through the vadose zone. However, the risk of groundwater contamination is reduced as the depth in the vadose zone increases. Decomposition is dependent on temperature, soil type, microbiological activity, and the half-life of the pesticide.

Organics

Common organics found in runoff are combustion by-products such as fluoranthene and pyrene. They undergo volatilization, microbial degradation, and sorption as they percolate through soil, which reduces their concentration significantly. Contamination occurred most frequently in areas with pervious soils such as those with a high percentage of sand and gravel, as well as areas with a shallow water table.

Pathogens

The highest concentrations of bacteria and viruses in groundwater occurred at locations where the water table was near the land surface. Factors that affected survival of pathogens include soil pH, antagonism from soil microflora moisture, temperature, and organic matter. Lower pH values decreased the lifespan of the microorganisms while lower temperature increased their survival time. Adsorption to soil particles was promoted by increased cation concentration, low pH, and low soluble organic concentrations. In general, dry soils and high temperatures eliminated both viruses and bacteria.

Metals

At neutral pH values, most metals adsorb onto particles. As a result, metals typically do not migrate through the vadose zone. However, at some sites, such as one commercial dry well site in Arizona, nickel, chromium, and zinc concentrations exceeded regulatory limits in the soil while the concentration of manganese exceeded regulatory limits in the groundwater. Because manganese concentrations were not high in the soil, it is unclear whether the manganese got into the groundwater through the dry well or by some other means. An upgradient monitoring well was not used in this study so it was not possible to determine if the dry well contributed to the elevated levels of manganese.

Salts

Salts were usually a problem in cold climates where they are used as de-icing agents on roads. In such areas, chloride has a high groundwater contamination potential irrespective of the pretreatment, infiltration, or percolation practices used.

Conclusion

Pollutants with high abundance in stormwater, high mobility in the vadose zone, and high soluble fractions posed the greatest risk to groundwater quality. Nitrate, fluoranthene, pyrene, and chloride are among the contaminants that are problematic. Rapid infiltration mechanisms such as dry wells should be employed with pretreatment facilities to remove contaminants and sediments. This will both reduce the risk of contaminating the groundwater and increase the lifespan of the infiltration practice.

The impact of intentional stormwater infiltration on soil and groundwater

Barraud, S., Gautier, A., Bardin, J.P., and V. Riou. 1999.. Wat. Sci. Tech 39 (2): 185-192.

Purpose

This study examined the influence of the age of the dry well on the risk of groundwater contamination.

Background

The study was conducted in Valence, France. Subsurface geology was composed of coarse alluvium; groundwater depth was approximately 4 meters. Two dry wells, one 30 years old and another two years old, that were evaluated in this study were situated on the same street. They drained roads and an open space.

Methods

Dry Well Design

The 30 year old dry well was rectangular and drained a catchment area of 1355 m². The two year old dry well was cylindrical drained a catchment area of approximately 290 m². The bottoms of the two dry wells were about 0.4 meters above the water table.

Sampling and Analysis

Stormwater, soil, and groundwater sampling was conducted throughout a one year period. Stormwater was collected by continuous sampling at the newer dry well. Soil and groundwater samples were collected using three piezometers. The older dry well was monitored by a piezometer installed 1.5 meters downgradient while at the newer dry well, one piezometer was placed 10 meters upgradient and a second was 1.5 meters downgradient. Samples were analyzed for total nitrogen, zinc (Zn), lead (Pb), cadmium (Cd), chemical oxygen demand (COD), total organic content (TOC), suspended solids (SS), aromatic hydrocarbons, mineral oils, pH and conductivity.

Results/Discussion

Stormwater samples were reported to contain “typical pollutants at average concentrations for the area.” Concentrations of Pb, Zn and SS concentrations fluctuated from storm to storm. Lead, which has a Maximum Contaminant Level (MCL) of 0.015 mg/L, had a mean concentration of 0.09 mg/L in stormwater. It was the only contaminant to exceed the MCL in the stormwater.

In soil samples, metal concentrations were elevated at both sites, ranging between 100 – 1500 mg/kg. At the newer dry well site, metal concentrations decreased sharply at soil depths greater than 10 cm below ground surface. The older dry well had a similar decrease in concentration at about 1 meter below ground surface. The soil just below the dry wells contained detectable concentrations of hydrocarbons. Toluene was detected in the older dry well, almost in direct contact with the groundwater.

Groundwater samples did not contain pollutants that exceeded the MCL. Groundwater analyses under dry weather conditions showed trace amounts of Zn, Pb and long-chain heavy hydrocarbons. Organic pollutants, COD, and TOC concentrations were low and nitrate concentrations were high, around 60

mg/l. During storm conditions groundwater analyses detected high levels of organic pollutants and nitrogen. Heavy metal concentrations of Zn and Pb increased as well but were still lower in the groundwater measurements than at dry well entry points. All heavy metal concentrations detected in groundwater measurements were below drinking water standards.

Conclusion

Metal and hydrocarbon concentrations were elevated in the first few centimeters below both dry wells, then fell off rapidly. While there were small increases in heavy metal concentrations in the groundwater, none of the pollutants in groundwater exceeded the MCL. This indicates that infiltration through the dry wells had not significantly degraded groundwater quality. The authors noted that it would be necessary to extend this study over longer periods, to get more representative information.

OEHHA Note: References to MCLs were added by OEHHA. MCLs and other health advisory reference values refer to California values for comparative purposes.

Evaluation of Urban Runoff Infiltration and Impact to Groundwater Quality in Park Ridge, Wisconsin

Lindemann, J. 1999. College of Natural Resources, University of Wisconsin, Stevens Point, Wisconsin.

Purpose

The purpose of this project was to determine the impact of stormwater infiltration through dry wells on groundwater quality.

Background

The study site was the City of Park Ridge, WI, a small town that disposes its stormwater using dry wells and roadside ditches. The area's surface geology consisted of gravel and sand deposits while its subsurface geology consists of granite and sandstone. Groundwater depth was approximately 30 feet.

Methods

Dry Well Design

Dry well depths varied between 5 and 8 feet. Infiltration holes ran across the entire length of the pipe. The opening at the top was covered with a grate and the bottom was open, resting on gravel. There was no pretreatment. No further details regarding dry well design were provided.

Runoff, Sediment, and Groundwater Analysis

Runoff samples were obtained by suspending a pail beneath the upper dry well grate and collecting the water when the pail was overflowing during or after a rain event. Samples were taken from five dry wells three times for one year during the spring. Sediment samples were taken by drilling a core from the bottom of the dry wells. The core lengths varied, depending on the amount of sediment present.

Groundwater samples were obtained from 12 monitoring wells; six were downgradient of the dry wells, two were collected from a pipe that extended through and below the bottom of the dry well, three were in or next to roadside ditches, and one was located upgradient of the dry wells and ditches.

Groundwater sampling was conducted over a two year period; ten times during and up to 16 days after rain events.

All water samples were analyzed for polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), nitrogen, chloride, sodium and iron. To further evaluate groundwater quality, water samples were collected from 77 private wells and analyzed for pH, conductivity, alkalinity, total hardness, hardness, nitrogen, chloride, sodium, and iron.

Results/Discussion

In stormwater runoff samples, concentrations of PAHs were consistently elevated. For example, benzo[a]pyrene concentrations were 2 – 3 times above the Maximum Contaminant Level (MCL) in most samples. The runoff in the dry well closest to a major highway had the highest concentrations of PAHs, suggesting that motor vehicles were a major source. Concentrations of VOCs were consistently low; benzene and carbon tetrachloride were the only VOCs that exceeded MCLs, and then in only one sample. In sediment samples, concentrations of PAHs were consistently elevated. For example, indeno[1,2,3-cd]pyrene was detected at a concentration of 1.8 ug/kg, 21 times greater than the

Wisconsin health regulatory level. Other contaminants that exceeded regulatory levels included benzo[a]anthracene, chrysene, benzo[b]fluoranthene, and benzo[a]pyrene. In all groundwater samples, the concentrations of PAHs, VOCs, and metals were below MCLs. This suggests that stormwater infiltration through the dry wells had not compromised groundwater quality. It also suggests that the sediment in the bottom of the dry wells was storing PAHs, because PAHs were present in stormwater and sediment samples, but not in groundwater samples. In samples from private wells, the water quality was generally acceptable. Nitrate + nitrite slightly exceeded the MCL in one sample. No other pollutants exceeded MCLs. However, sodium concentrations frequently exceeded the 20 mg/L health advisory level.

Conclusion

The results of this study suggested that stormwater infiltration through dry wells did not degrade groundwater quality during the two year period of this study. The results also suggested that PAHs were adsorbed by sediment in the bottom of the dry wells. The author recommended that sediment in the bottom of the dry wells be sampled and disposed of every few years. It was also suggested that signs be put up deterring the public from dumping waste products into dry wells.

The Class V Underground Injection Control Study: Volume 3, Stormwater Drainage Wells.

US EPA. 1999. Office of Ground Water and Drinking Water. 96 pgs.

Posted at: <https://www.epa.gov/uic/class-v-underground-injection-control-study>

Purpose

This study was conducted in response to a lawsuit filed by the Sierra Club against the US EPA regarding concerns that the EPA's Underground Injection Control (UIC) program did not adequately protect groundwater from the risk of contamination associated with the use of dry wells. As a result of the lawsuit, the EPA was required to determine if existing federal UIC regulations were sufficient to mitigate risks to underground sources of drinking water (USDW), if additional federal regulations were necessary, and how each type of well should be regulated.

Background

Incidents of contamination of groundwater have been reported in multiple states that could be linked to dry wells. Several studies that were performed, however, did not clearly distinguish contamination from storm water drainage wells versus more general, nonpoint source pollution. This report reviews existing information to assess the risks associated with the use of UIC and the need for additional regulation.

Methods

The EPA study reviewed existing literature, conducted a survey of state and regional UIC programs, discussed common pollutants in runoff, and the design and location of existing UICs. The survey reported 71,015 documented wells, although the actual number is estimated to be around 250,000 wells. The number of documented wells is significantly lower than the estimated number of wells because state officials believe their official inventories are out of date due to insufficient coordination between state and local agencies, wells on private property, wells built before state agencies had primacy for Class V wells, and improperly plugged wells that may still be in operation. This review will focus on those sections of the 96-page report that address risk to groundwater quality.

Results

Common Characteristics of Stormwater Runoff

A variety of contaminants are commonly found in stormwater. Suspended material is the most common stormwater pollutant. Although suspended solids are mostly inert constituents, they may still pose health risks when pollutants such as heavy metals, organic compounds, and microorganisms are adsorbed to them. Nutrients are another common contaminant in stormwater. The various forms of nitrogen are highly soluble in water, which contributes to its common presence in groundwater. Metals pose the highest potential for USDW contamination because of their prevalence and potential toxicity. Lead, zinc, and copper are commonly detected at high concentrations in urban stormwater. Other contaminants detected included chromium, cadmium, arsenic, and nickel. While many metals can be removed with filtration and sedimentation, metals that are not dissolved can also adsorb onto suspended sediment and migrate to groundwater through fractures or porous soil.

Common pesticides found in stormwater runoff include chlorophenoxy herbicides such as 2, 4-D, chlorinated pesticides (e.g., alachor, aldrin, and chlordane), and organophosphates such as diazinon and

malathion³. A USGS study conducted in the early 1990s detected 62 volatile organic compounds (VOCs) at low concentrations (below the MCL) in urban stormwater. Another study conducted by the USGS in 1993 and 1994 on shallow and deep dry wells suggested UICs are a probable source of methyl tert-butyl ether (MTBE) groundwater contamination.

Bacteria and viruses are also found in stormwater runoff, most often originating from pet, bird and other animal feces on paved surfaces and yards. More densely populated residential areas contribute the greatest amount of bacteria to runoff. Coliform levels in runoff are 20 times higher in warm weather seasons than in cold. Fecal coliform in stormwater runoff commonly exceeds drinking water standards of 1 MPN/100 ml per month by a factor of 50 to 75.

Common Characteristics of Dry Well Design

Dry wells can be constructed in different ways but all involve excavating a hole to a depth where the bottom of the well lies above the seasonal high water table level so the well remains dry except when receiving runoff. The hole is frequently backfilled with gravel; drainage nets are sometimes set at the bottom of the well. Dry wells are often constructed with catch basins that collect water before it enters the well. They can serve as a trap for sediment and any adsorbed pollutants prior to runoff entering the well. Depending on the design, catch basins can also prevent floating oil and petroleum from entering UIC.

Damage to Underground Drinking Water Sources associated with UICs

A nationwide review of groundwater contaminant incidents was conducted to evaluate the history of accidents associated with the use of UICs. The following table summarizes the findings:

Incidents of Groundwater Contamination Associated with Stormwater Drainage Wells

Location	Incident	Contamination Type
Morgan Hills, CA	Glass Tek discharged industrial waste and wash water containing volatile organic solvents into SW retention pond containing 3 dry wells.	A groundwater plume of organic solvents (TCE, cis-1,2-DCE, and TCA) extending 2,500 ft. long and 200 ft. deep.
Modesto, CA	Six stormwater drainage wells were closed after high levels of metals and motor oil were detected. Illicit dumping is believed to be the source of contamination.	Chromium, copper, lead, zinc, and motor oil were detected.
Los Gatos, CA	Allegedly surface spills of fuel and other contaminants washed into a dry well at the Southland Corp; gasoline/other chemicals originated from the commercial site and contaminated groundwater.	Gasoline and other industrial chemicals.
Mountain View, CA	Groundwater and soil within 3 miles of drinking water wells were contaminated via dry wells. Unauthorized dumping of solvents by the Jasco Chemical Corp. is believed to be the source of contamination.	Dichloromethane, pentachlorophenol.

³ While these pesticides were commonly found in stormwater at the time this report was released, today the most common pesticides found in runoff are pyrethroids, fipronil, and neonicotinoids.

Location	Incident	Contamination Type
Fairborn, Ohio	21,000 gallons of fuel oil was accidentally released from a storage tank and overflowed the dike into two storm wells at a petroleum distributing facility in 1989.	Groundwater monitoring wells revealed up to 8 ft. of oil resting on the water table six months after the incident.
Hutchinson, Kansas	Water effluent with a tar and diesel fuel mixture entered dry wells from downspouts causing the temporary closure of a municipal supply well.	Low levels of xylene, dichloromethane, and ethylbenzene were detected in the water effluent and dry well.
Waupaca County, Wisconsin	In 1988, runoff from a school's roof and kitchen garbage disposal entered and a contaminated stormwater drainage well.	Total coliform and fecal coliform were detected in the drinking water supply.
McChord Air Force Base, Tacoma, Washington	In 1980, the City of Lakewood found organic solvent contamination in drinking water supply wells due to sludge and organic waste solvents that were deposited in leach pits and storm drains.	Trichloroethylene, chloroform, trans-1,2-dichloroethylene, and tetrachloroethylene found.
Oak Grove, Kentucky	In 1988 the city's water plant was shut down for 3 days after an intense storm due to a sharp spike in turbidity. This spike was likely due to a problem with one of the several stormwater drainage wells in the area, a sinkhole or a cave.	Raw turbidity increased from 6.5 NTU before the storm to 1,750 NTU after the storm. The plant reopened when levels dropped to 13 NTU.
Valparaiso, Indiana	Runoff from road salt piles flowed into stormwater drainage wells causing a chloride plume in the shallow aquifer that migrated towards the city's public water supply.	Sodium chloride levels were more than twice the average concentration.
Bellevue, Ohio	Raw sewage disposed of in wells (cesspools), as was a common practice from the late 1800s to 1971. An area of groundwater 5 miles wide and fifteen miles long was contaminated and alternative drinking water supplies such as rain water capturing cisterns were required.	Coliform levels in wells exceeded safe drinking water levels. Mud and debris clogged private drinking water wells.
Fairfield, OH	Ohio EPA study found people disposed of waste in the 2,900 drainage wells and basins in Fairfield. Contaminants unlikely to be attenuated in the sand and gravel of the aquifer.	Used oil, antifreeze and other wastes and hazardous material were routinely emptied in wells.

Relationship between Land Use and Pollutant Concentration in Stormwater Runoff

Multiple studies have found associations between site location and/or land use and the composition of stormwater runoff. For example, one study found higher concentrations of total hydrocarbons in oil/water separators near gas station and parking areas than in those in residential areas. Pitt et al. (1996) describes urban "hot spots" such as industrial sites, gas stations and convenience store parking lots in which runoff contained higher concentrations of trace metals. The Arizona Department of Water Resources (1993) similarly found that runoff from industrial land use areas typically produced more contaminated runoff. However, the US EPA's Nationwide Urban Runoff Program study, which analyzed urban runoff samples for 120 primary pollutants, found that variability in runoff constituents between

sites can be more consistently explained by high variability in the size and duration of storm events than by site location and land use variability.

Best Management Practices

Siting

Minimum Setback Distance from Surface Waters: Horizontal separation between a stormwater infiltration system and down-gradient surface waters provides filtration as the water passes through a soil layer before entering waterways. Additionally, horizontal separation provides another barrier of overland distance should the infiltration system become clogged and create pooling at the surface. Local by-laws often require a buffer zone around water bodies or wetlands and the most effective systems have a buffer zone with at least a nine-minute residence time, the time it takes water to travel through the buffer zone to the water body or wetland. State and local regulations contain minimum separation between septic systems and surface waters ranging from 40-100 ft. and greater distances from surface drinking waters.

Minimum Setback Distance from Drinking Water Well: No one value for recommended distance between infiltration devices and drinking water wells can be determined because contaminant transport is dependent on local climate, geology, and land use. Factors such as the depth of the injection well, volume and rate of precipitation, concentration of contaminants in the runoff, soil characteristics, groundwater flow and pH, and water table fluctuations all impact contaminant transport. These factors must be considered when building a stormwater drainage well near a drinking water well.

Minimum Separation from Water Table: A minimum separation between the bottom of the stormwater drainage well and the seasonal high groundwater table is often required or recommended because the soil layer sequesters contaminants. Seasonal high water table levels can be determined by analyzing soil strata for evidence of oxidation. No specific separation distance was identified.

Prohibition from Some Areas of Concern: Local or state agencies as well as Indian tribes may prohibit the construction of UICs in drinking water well protection zones, Outstanding National Resource Waters, areas adjacent to wetlands, brownfields, contaminated site clean-ups, and landslide prone areas.

Soil Performance Specifications: Soils with a high silt/clay content are the most effective at removing or attenuating contaminants from stormwater due to their low permeability and sorptive properties. However, many design specifications advise not to build infiltration devices in fill or soils with high silt/clay content and, thus, slower infiltration. These specifications focus on preventing well failure due to clogging and overflow rather than on groundwater protection. The attenuation ability of a site's soil must be balanced with its infiltration capacity when designing and siting a stormwater drainage well. This requires analyzing the anticipated flow rates and volume of runoff along with which contaminants are likely present in runoff and their concentrations.

UIC Design

Pretreatment features remove sediment and/or contaminants from the runoff before it enters the UIC to prevent clogging and to reduce risk of groundwater contamination. Engineered pretreatment features use materials and objects to actively remove or trap contaminants. These include oil/grit

separators, oil and grease separators, and catch basin inserts. Passive pretreatment includes structural and vegetated features that use gravity, water flow, infiltration, and biological processes to filter stormwater runoff. Passive pretreatment techniques include filter strips, vegetated swales, vegetative infiltration basins, infiltration trenches, sand/gravel filters, wet ponds, stormwater wetlands, and porous pavements.

Studies have shown that passive pretreatment features are generally highly effective at removing sediments, lead, copper, and zinc (40-95% removal) from runoff, but less effective at removing water soluble pollutants such as nitrogen, nitrate, and phosphorus (25-90% removal). Porous pavements have the highest removal rates of the studied pretreatment features, but also have limited applicability. Infiltration trenches have the next highest removal rates, followed by sand filters, grassy swales, and extended detention basins. Catch basins have the widest ranges of removal rates. These variations result from season fluctuations and clogging that occurs over time.

Operational BMPs

Various management practices can be used to minimize contamination risks to USDWs, particularly in industrial areas, construction sites, highways, and urban settings. Using a physical barrier to separate the source of the contaminant from contact with rain and/or runoff is one operational BMP that can be effective. These methods include the use of sumps, covering materials, and containment dikes. Pollution prevention planning is another important operational BMP to consider. Developing a stormwater pollution prevention and a spill response plan helps to mitigate pollution threats, reduce future costs of environmental compliance or cleanup, and improve stormwater management efficiency. Land uses and business activities around which UICs should not be located include vehicle and equipment fueling and maintenance and hazardous material loading. If the wells are already in place, however, BMPs such as installing spill/overflow equipment on storage tanks, building awnings or roofs over refueling/maintenance/washing/loading areas, and recycling wash water can help to prevent contaminant movement to USDWs.

Maintenance, inspection, and cleaning of infiltration and pretreatment features is also important to prevent a system failure which could lead to contamination of groundwater. Closing UICs may be necessary if cleaning techniques do not prevent clogging.

A monitoring system to analyze contamination in stormwater and groundwater is important for pollution management and to evaluate the efficacy any pretreatment devices. The relatively unpredictable nature of storm events, the local hydrology, and the build-up of contaminants in the vadose zone and soils below infiltration basins should be considered in creating a monitoring strategy.

Education and Outreach

Education and outreach help to raise awareness about the risks of contaminating groundwater, to prevent intentional contamination, and to encourage compliance with regulations that protect water resources.

Regulatory Requirements

Under the Safe Drinking Water Act (SDWA), the US EPA regulates UICs. The EPA administers 19 UIC programs in states/territories and Tribal lands, while the remaining states have primacy, or primary enforcement responsibility, over their UIC programs. Under the SWDA, operators of injection wells are prohibited from any activity that causes contamination of USDWs. If well operators provide inventory information about their wells and do not engage in activities that threaten USDW, then their well is considered *authorized by rule*. If UICs are placed in higher risk sites or if the number of wells is very large, then *permits* may be required. Other federal programs such as the National Pollution Discharge Elimination System (NPDES), the Coastal Zone Management Act, and some Federal Highway Administration guidelines indirectly influence stormwater drainage well management. State and local programs may also regulate UICs by requiring buffer zone requirements, minimum setback distances from drinking water wells, and design requirements based on local conditions. Some states have sizeable UIC programs, such as Arizona. For example, the Arizona Department of Environmental Quality requires businesses that handle hazardous chemicals to obtain an Aquifer Protection Permit (APP). To receive a permit, APP applicants are required to provide in depth information about the UIC design and operations, pollutant characteristics, baseline data, hydrogeologic characterization, and closure strategy. Monitoring requirements and construction standards for wells requiring an APP are established on a case-by-case basis, usually reserved for more hazardous locations.

Conclusion

The report concluded that UICs can be used safely without great risk to drinking water sources. Proper siting and pretreatment can greatly reduce the risk of contamination. Steps that can be taken to reduce risk include following recommended design specifications, including the use of pretreatment, siting wells away from high risk areas, and monitoring to ensure the quality of stormwater. Additionally, providing guidance documents and BMP recommendations, developing spill prevention plans, understanding the local geology, and educating the public on groundwater contamination risks can further minimize risk of groundwater contamination. Many states have guidance documents on dry well use and maintenance even if strict regulations are not enforced. Educating commercial, residential, and industrial users about the threats to and consequences of groundwater contamination also mitigates risks. Although some states' UIC programs are stronger than others, many have additional regulations and recommendations beyond what the US EPA dictates. In those states where the UIC programs are less effective, stricter and more detailed requirements for obtaining stormwater drainage well permits, along with greater enforcement, would significantly improve the programs and mitigate groundwater contamination risks.

OEHHA notes:

Dry wells are often designed so the bottom of the well lies above or in a clay unit in the vadose zone, which can aid in contaminant attenuation.

Oregon and Washington both have well developed UIC programs that evolved after this report was prepared.

After the full study was conducted and reviewed, the US EPA determined that new or additional federal underground injection control regulations for all sub-classes of Class V injection wells were unnecessary (Federal Register, 2002).

Pilot Evaluation Subsurface Stormwater Disposal Facilities

Adolfson Associates. 1995. Tacoma-Pierce County Health Department, Tacoma-Pierce County, Washington.

Purpose

This study was conducted to evaluate the pollutant removal effectiveness of three stormwater infiltration designs.

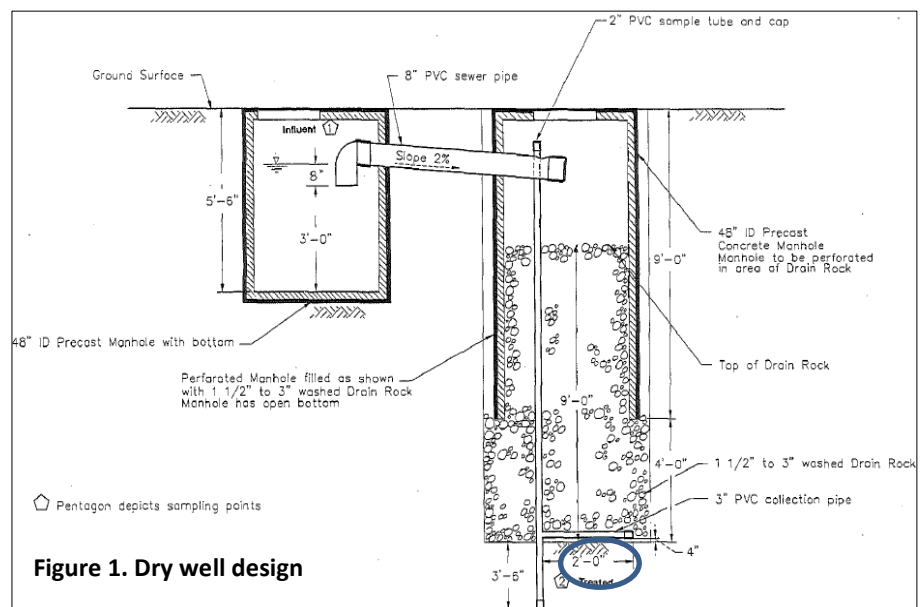
Background

Pierce County has used open-bottom manholes to dispose of urban runoff for over 30 years. Concern about water quality in the Clover/Chambers Creek aquifer, which supplies drinking water to approximately 270,000 people, prompted the district to develop and research the pollutant removal effectiveness of three infiltration designs. The areas' surface geology consists of till in the north, which is low in permeability, and coarse sand and gravel deposits in the south, which provides for direct recharge of precipitation to the aquifer. Subsurface geology consists of alternating glacial and non-glacial strata. Groundwater depth ranged between zero to greater than 100 feet.

Methods

Site 1 was installed with an infiltration facility that consisted of a 60 inch diameter sedimentation/oil separation chamber and a 25 foot long drainfield. A riser pipe in the chamber, wrapped with filter fabric to trap and prevent migration of fine sediments to the drainfield, was connected to a perforated distribution pipe in the drainfield. At this site, samples were taken from stormwater entering the system, treated water from above (Treated 1) and below (Treated 2) the riser pipe in the sedimentation chamber, and groundwater from a monitoring well installed in the uppermost aquifer, approximately 20 feet below ground surface. Site 2 was installed with an infiltration facility (Figure 1) that consisted of a 42 inch diameter sedimentation manhole which discharges into a perforated 48 inch diameter dry well. The dry well was lined with filter fabric (NICOLON 40/10) and filled with drain rock. At this site, samples were taken from

stormwater entering the system and from treated water immediately below the infiltration manhole (Treated), as shown in Figure 1. A monitoring well was not installed at this site due to site constraints. This site drains a one acre, largely commercial area. There was an auto repair shop immediately adjacent to the sedimentation manhole. Site 3 was



installed with an infiltration facility that combined a grassy swale with a sedimentation/oil separation chamber and an infiltration trench. At this site, samples were taken from stormwater entering the system, the swale, and a monitoring well extending 20 feet below ground surface. Sampling at the three sites was conducted throughout a four year time period for 18 storm events and analyzed for total and dissolved metals (arsenic (As), copper(Cu), lead(Pb), and zinc(Zn)), chemical oxygen demand (COD), total petroleum hydrocarbons (TPH), total suspended solids (TSS), fecal coliform, nitrate, and total nitrogen.

Results/Discussion

All pollutants were detected in at least some of the influent stormwater samples at each of the three sites. At Site 1, the concentration of metals, TPH, coliform, nitrate, and total nitrogen in stormwater samples were relatively the same as in treated samples. This suggests that this facility is not efficient at removing pollutants from runoff and therefore should not be installed in areas where pollutant removal is a priority. The background groundwater sample, which was taken before the facility was installed, had a higher concentration of pollutants than any sample taken at this site. This suggests that the Clover/Chambers Creek aquifer had already been contaminated by sources other than this infiltration facility.

At Site 2, initial results indicated potentially significant removals of total metals and TPH. However, after the first three sampling events, this pattern was reversed; total metal (As, Cu, Pb and Zn), TPH, TSS, and total nitrogen concentrations were two times higher in treated samples than stormwater samples. For example, the mean copper concentration was 31 ppb in stormwater samples and 139 ppb in treated samples. This pattern persisted over the course of the study and may be attributed to one or a combination of several factors, including pollutant-laden sediment deposition in or just below the dry well and/or significant chronic as well as acute loading of contaminants.

At Site 3, the facility provided consistently significant removal of total metals and TPH. For example, total metal concentrations in runoff were reduced by 45 to 80% while TPH concentrations in runoff were reduced by 83%. The predominant removal mechanism was determined to be infiltration through the vegetation layer and upper six inches of topsoil. All pollutants were detected at some level in some of the groundwater samples, but most of them were also detected in the background groundwater sample. Only TSS concentrations showed a positive trend in the groundwater throughout the course of the study. This suggests that stormwater infiltration through the facility did not contribute to increased pollutant concentrations in the groundwater.

Conclusion

The key conclusion from the study is that the dry well design at Site 2 did not reduce pollutant concentration in the influent stormwater. The design at Site 1, which had a pretreatment to control sediment, produced similar results. As a result, the authors recommended that neither design should be used in areas where stormwater is likely to carry a high amount of pollutants. In contrast, the infiltration design at Site 3, which included an infiltration trench with pretreatment, was effective at removing total metals and TPH. Of the three designs evaluated in this study, the design at Site 3 appeared to be the most effective in removing pollutants.

The groundwater recharge and pollution potential of dry wells in Pima County, Arizona

Wilson, L.G., Osborn, M.D., Olson, K.L., Maida, S.M., and L.T. Katz. 1990. Groundwater Monitoring & Remediation. Summer: 114-121.

Posted at: http://arizona.openrepository.com/arizona/bitstream/10150/306470/1/wrrc_250_w.pdf

Purpose

The two main goals of this study were to identify possible groundwater pollution from dry wells collecting urban runoff and the groundwater recharge potential of dry wells.

Methods

Four sites at high risk of pollution from existing dry wells were selected for this study. Each dry well was composed of a concrete-lined sedimentation chamber from which water overflowed into a gravel-packed dry well. The dry wells were located at a commercial site, an industrial site, and two residential sites. The dry wells were between 25 - 35 feet below ground surface (bls) while the water tables were between 130 - 250 feet bls. At each site, one sample of runoff and one of sediment were collected at an unspecified time of year. A grab sample of runoff was collected at the entrance to the dry well chambers. Sediment from the sedimentation chambers was collected in beakers using clean collection methods. To monitor groundwater and vadose zone water, a borehole was drilled within 3 feet of each of the dry wells. Vadose zone samples were collected at various depth intervals from all wells. Perched groundwater samples were collected from the commercial and residential sites. A single water table sample was collected from one of the residential sites. Pollutants analyzed in the samples included volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), phenols, pesticides, and heavy metals. Recharge potential was inferred from previous studies.

Results

The recharge potential was not quantified and was unverifiable due to lack of monitoring wells. It was inferred that dry wells facilitate more recharge than finer grained soils in the subsurface.

Volatile organic compounds (VOC) were detected in samples from the perched aquifer at the commercial and residential sites, however, the concentrations were more than two times below the Maximum Contaminant Levels (MCLs). VOCs were also found in the sediment samples from at all three types of sites. At the industrial site, xylenes were detected at a concentration 17 times higher than MCLs.

Polycyclic aromatic hydrocarbons were detected at levels greater than the MCLs in the stormwater runoff and sediment chamber samples. Samples from the perched aquifer and water table had PAH concentrations below the MCL. For example, the benzo[a]pyrene concentration was 220 times greater than the MCL in the stormwater sample but below the detection limit in groundwater samples. Notably, the instruments used for this study had higher reporting limits than the MCLs for a number of contaminants; therefore, it wasn't always possible to determine if there was an exceedance. Trace amounts of pesticides were found in stormwater runoff and sedimentation chamber samples. Pesticide contaminants were not found in excess of MCLs in the perched aquifers or groundwater samples at any site.

Inorganic pollutants were not found above the detection limit in the vadose zone samples from any site. In contrast, heavy metals were found in the vadose zone at all sites. Those with the highest concentrations were nickel, chromium and zinc.

Conclusion

The results of this study are inconclusive regarding the risk of groundwater contamination. It appears that the instruments lacked sufficient sensitivity to detect various contaminants at MCL concentrations. Additionally, the results of this study were based on a single sampling event, which limits the confidence in the results. The study does show however that the sedimentation chambers were effective at containing the majority of the contaminants and preventing them from polluting the groundwater.

PUBLISHED BETWEEN 1980 – 1990

The groundwater pollution potential of dry wells in Pima County, Arizona

Wilson, L. G., M.D. Osborn, K.L. Olson, S.M. Maida, and L.T. Katz. 1989. The Water Resources Research Center, University of Arizona.

Purpose

This study was conducted to evaluate the potential of stormwater, when infiltrated through dry wells, to contaminate groundwater in Pima County, Arizona.

Background

Dry wells are commonly used to dispose of stormwater in Tucson, Arizona. Concern about the potential of infiltration through dry wells to contaminate groundwater prompted the City of Tucson to fund a two-phased study. Phase One inventoried dry wells in the area and assessed pollutants in the settling chamber sediment. Based on the results from the first phase, the worst case industrial, commercial, and residential dry well sites were selected for further analysis in Phase Two. This paper presented the second phase of the study.

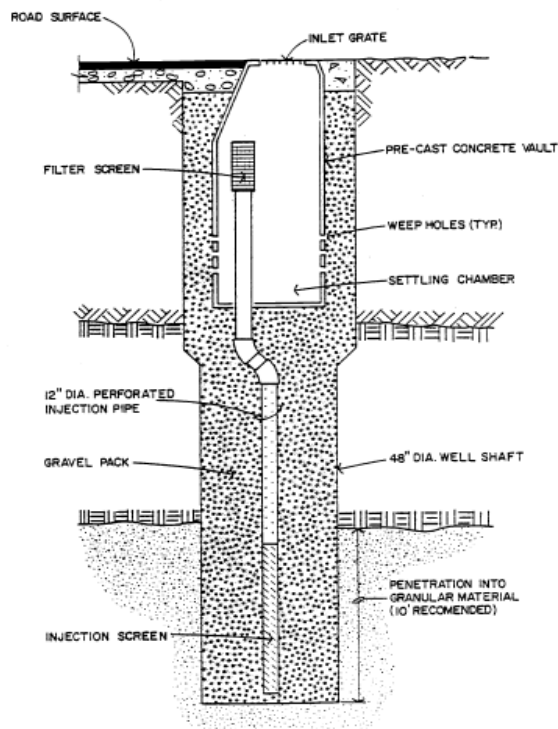


Figure 1. Drawing of typical dry well constructed in Tucson, AZ.

Methods

The general design of dry wells in Tucson is shown in Figure 1. At the industrial site, the dry well was made up of an upper sediment chamber that extended 20 feet below ground surface (bls) and a lower gravel packed shaft that extended 35 feet bls. The dry well was two years old and drained a parking lot, roof, vacant lot, public street, and minor landscaping areas. Groundwater depth was 130 feet. At the commercial site, the dry well was back-filled with sediment to within 10 feet of the surface. The dry well drained an outdoor garden supply center with potted plants and a parking lot. Groundwater depth was 110 feet. At the residential site, the dry well was made up of a settling chamber that extended 20 feet bls and included a gravel packed shaft that extended 25 feet bls. The dry well was three years old and drained an asphalt parking lot, rooftops, and grassed and landscaped areas. Groundwater depth was 250 feet.

At the three sites (industrial, commercial, and residential), stormwater, sediment, vadose zone and groundwater sampling was conducted. Stormwater was collected using grab samples of runoff at the industrial and commercial sites. Sediment samples were collected from the upper four inches of accumulated sediment in the dry well settling chamber. To learn about the vadose zone geology, a borehole was drilled beside each dry well and samples were taken from 15 to 100 feet bls at 2.5 to 20 feet intervals. The samples were analyzed for

geologic composition and contaminants. When possible, samples of perched groundwater and groundwater at the water table were taken from the borehole using bailers. If groundwater samples could not be obtained from the boreholes, samples were taken from nearby wells. Between 1 – 3 samples of each media (runoff, sediment from dry well, vadose zone, and groundwater) were collected from each site over a three-year period. Samples were analyzed for oils and grease, priority metals, and a variety of organics such as styrene, pentachlorophenol, and chlorophyrifos. No statistical analyses were performed on the data.

Results/Discussion

The geology at the industrial site consists of well-sorted fine sand between 0-25 feet bls, of medium to coarse sand between 25–40 feet bls, and of silt and clay from 40-140 feet bls. Two perched aquifers were contained in the first 60 feet bls. The one stormwater runoff sample collected from this site was relatively pollutant free, containing only slight amounts of zinc, mercury, and the semi-volatile compound pyrene. This contrasted with sediment collected from the sedimentation well, which contained small amounts of a variety of organic and metal contaminants. Two samples of dry well sediment were collected about 2 months apart. Oil and grease were present in the largest quantity, with a concentration of 1,100 mg/kg. Vehicular exhaust products such as xylene were found at a concentration of 170 mg/kg. A variety of polycyclic aromatic hydrocarbons and a number of phthalates were also found adsorbed to the sediment. Small amounts (from trace to < 10 mg/kg) of a variety of metals were identified, however, none were consistently elevated. Zinc and copper, two commonly found metals linked to tire and brake pad wear, were among the metals identified. The analytical methods used for metal analysis changed so comparison of the first and second sample results is difficult. Vadose zone samples did not contain detectable levels of organics, however trace quantities of metals were identified. Six serial samples were collected between 35 and 140 feet bls and no trends related to depth were identified. In the groundwater sample, which was obtained from a nearby public supply well, some metals and halogenated organics were detected. However, none exceeded regulatory standards. Taken together, these results suggest that stormwater infiltration through the dry well at the industrial site did not alter groundwater quality for the two year period of monitoring

The geology at the commercial site consists of well sorted sandy, clayey silt between 0-30 feet bls, of poorly sorted sand and gravel from 30-60 feet, and silt/clay matrix from 60-115 feet bls. Similar to the industrial site, the single stormwater runoff grab sample contained few pollutants. Total chromium was the only metal detected in the sample. Few organics were detected. In the two sediment samples collected from the dry well, there was five-times as much oil and grease compared to the industrial site, ranging from 2700 – 4300 mg/kg. Among the semi-volatiles, a number of phthalates were detected each year, including bis[2-ethylhexyl] phthalate (DEHP), which has an MCL of 4 mg/L. The concentration of DEHP in one sediment sample was 38 mg/kg. A few volatile compounds (VOCs), toluene and ethylbenzene, were also detected at low levels (< 2.5 mg/kg). When a duplicate sample was analyzed at a different laboratory, all phthalates were below detection limits and the herbicide 2, 4-D was detected at < 1 mg/kg. Two years after samples were collected for organic analysis, three sediment samples were collected from the dry well for the analysis of metals. Elevated levels of zinc (135 – 140 ppm) and copper (35 – 50 ppm) were the primary metals identified; lead, nickel, and chromium were also

detected. Samples of vadose zone sediment showed no detections of the two VOCs found in sediment in the dry well. Similarly, only trace amounts of oil and grease were found in the vadose zone. Metals, most notably copper and zinc but also to a lesser degree, chromium, lead, and nickel, were detected in 13 vadose zone samples collected at intervals between 15 and 76 feet bls. The concentration of metals was highest at 15 feet bls and again at 60/76 feet bls. The existence of two clay lenses likely accounts for this finding. Two samples of groundwater were collected from the aquifer two years after the original dry well sediment was analyzed, and showed almost no detections of contaminants. Toluene was measured at 15 and 28 mg/L. Toluene and ethylbenzene were the only two contaminants detected in GW; the remainder were apparently attenuated in the vadose zone, volatilized, or degraded by microorganisms. Further, a leaking underground fuel tank existed about ¼ mile from the study site, so these two gasoline-related compounds could have their origin in that spill. Only trace amounts of any metal was detected in the groundwater.

The geology at the residential site consists of clay and caliche between 0-10 feet bls, of clay loam with pebbles, poorly sorted gravel, coarse sand, granite, pebbles, and varying amounts of fines between 15-50 feet bls, and of poorly sorted silty, sand, gravel, and pebbles between 50-130 feet bls. Stormwater sampling was not conducted at this site. Sediment sampling was performed once a year for three years. Similar to the industrial and commercial sites, oil and grease had the highest concentration of any pollutant. The only other organic detected was chlordane, a legacy pesticide, which had a concentration of 0.061 mg/kg. Sources of these pollutants include motor fuels, asphalt, and insecticide manufacturing. Zinc and Pb were detected at concentrations of 55 mg/kg and 2.3 mg/kg, respectively. Five other metals were detected at concentrations below 1.0 mg/L. Among them was arsenic (0.3 mg/kg) and total chromium (0.2 mg/kg). The most likely source of these metals is motor vehicles. No organics were detected in the vadose zone sediment. However, toluene and xylenes were detected in the single perched groundwater sample obtained at this site. Toluene, which has an MCL of 150 µg/L, had a concentration of 55 µg/L. The xylenes, which have an MCL of 1750 µg/L, had a total concentration 3.0 µg/L. Low levels of a variety of metals were detected in the vadose zone. In the perched aquifer sample, Cu, Fe, Mg, and Ni were detected at low levels (equal to or below 1.0 mg/L). The water table sample obtained from the borehole contained only toluene (3.7 µg/L, which is significantly below its MCL of 150 µg/L) and trace amounts of Fe and Mg. Overall, this suggests that infiltration through the dry well did not degrade groundwater quality during the three year period of monitoring.

Conclusion

The key finding of this study is that stormwater infiltration through dry wells did not significantly degrade groundwater at the industrial, residential, and commercial sites during the study period. These findings were supported by the lack of or very low level of pollutants detected in groundwater samples at all three sites. The authors speculated that volatile organics in stormwater underwent volatilization before or when they entered the dry well. Semi-volatile and non-volatile organics, on the other hand, appeared to undergo adsorption and biodegradation in the settling chamber of the dry well and in the vadose zone. Metals also appeared to be adsorbed in the vadose zone. The results indicate that vadose zone lithology may affect the potential for groundwater pollution. For example, no pollutants were detected in the groundwater sample at the industrial site, which was underlain by a massive clay

formation, while two volatiles were detected in the groundwater at the commercial site, where the vadose zone consists mainly of coarse-grained alluvium.

Effect of urban storm water injection by Class V wells on the Missoula aquifer, Missoula, Montana

Wogsland, K.L. 1988. University of Montana: 1-133.

Purpose

This study was conducted to evaluate the contamination impacts of urban runoff infiltration through Class V wells/dry wells on the Missoula, Montana aquifer.

Background

Approximately 2,700 dry wells have been installed in the City of Missoula. Approximately 200 million gallons of stormwater are infiltrated through dry wells each year. The aquifer is unconfined and extends to a depth of 100 – 200 feet. It is composed of: 1) an upper layer (10 – 30 feet thick) of interbedded boulders, cobbles, gravel, sand, and silt; 2) an intermediate layer (40 feet thick) dominated by silty sand with layers of coarse sand and gravel, and; 3) a basal layer (50 – 100 feet thick) dominated by interbedded gravel, sand, silt and clay.

Methods

To assess the quality of stormwater runoff, composite samples were collected at two sites while grab samples were collected from 2 stormwater outfalls and 4 parking lots. The quantity of pollutants entering dry wells annually was estimated using impervious drainage area, precipitation data, average runoff ratios (RORs), and event mean concentrations (EMCs). A ROR was calculated for each storm by dividing the volume of runoff by the volume of precipitation. An EMC, which is a flow-weighted calculation of sequential discrete samples used to characterize the concentrations contributed by the entire storm, was calculated for each pollutant. Vadose zone samples were collected from lysimeters installed at two dry well sites (Figure 1), one commercial and the other residential. To track the effect of the vadose zone on percolating runoff, the lysimeters were used to collect samples at 8 and 13 feet below ground surface

(bls) after runoff events. Groundwater samples were obtained from downgradient monitoring wells at each site as water levels were rising after runoff recharge. Sampling was conducted throughout a one year time period and samples were analyzed for total dissolved solids (TDS), salts (bicarbonate, sulfate, etc.) nitrate, oil and grease, and U.S. EPA organic priority pollutants

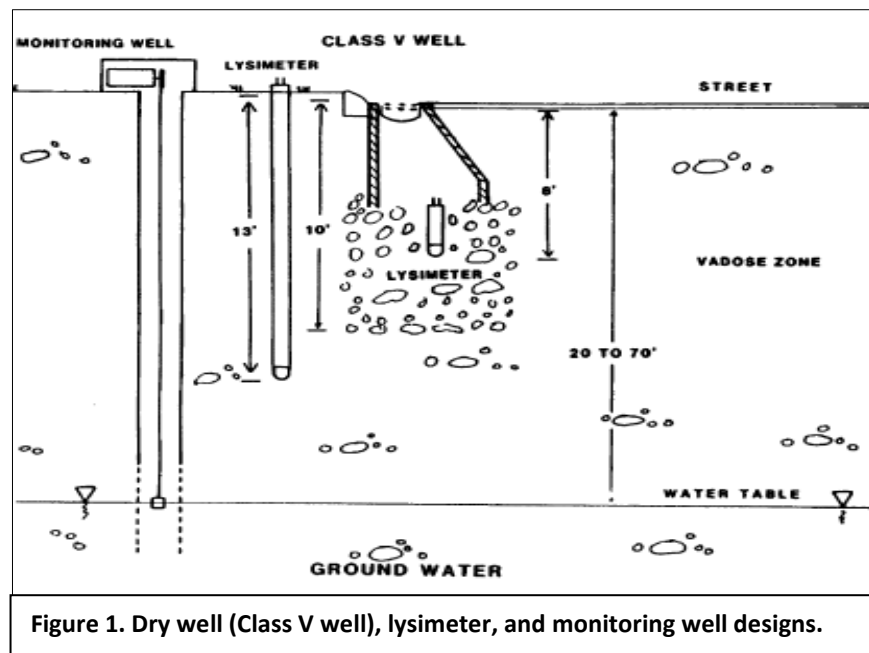


Figure 1. Dry well (Class V well), lysimeter, and monitoring well designs.

which includes toxicants such as benzo[a]pyrene, aldrin, chloroform, and other volatile and semi-volatile compounds.

Results/Discussion

The metals most frequently detected in runoff samples were iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), and lead (Pb). Cadmium, Cr, and Ni were less frequently detected while arsenic and mercury were not found. None exceeded the Maximum Contaminant Level (MCL). The quantity of each metal pollutant entering dry wells annually varied; of the metals detected, Fe was highest at 134.5 kg/year and Cu was lowest at 6.0 kg/year. Metal concentrations in vadose zone samples taken at 8 feet bls were lower than in runoff samples. Additionally, metal concentrations in vadose zone samples taken at 13 feet bls were lower than in vadose zone samples taken 8 feet bls. This indicates that the vadose zone had attenuated the metals. Probable reactions that may have caused this attenuation include adsorption, co-precipitation, and oxidation/reduction. Metal concentrations in the groundwater did not increase following infiltration of runoff through the dry wells. This suggests that runoff infiltration through dry wells had not increased the concentrations of metal pollutants in the groundwater during the one year study period.

The only ion that exceeded the MCL in runoff samples was Na (sodium), and it did so in snowmelt samples only. The quantity of each ion entering dry wells annually varied greatly; TDS was the highest at 140,430 kg/year, Cl (chlorine) was the second highest at 64,610 kg/year, and nitrate was the lowest at 230 kg/year. The average annual concentrations of TDS, Na, Cl, Ca (calcium), Mg (magnesium), K (potassium), nitrate, and bicarbonate were higher in vadose zone samples taken at 8 feet bls than in runoff samples. Additionally, the concentrations of TDS, Cl, Ca, Mg, Na, K, nitrate, and bicarbonate were higher in vadose zone samples taken 13 feet bls than in vadose zone samples taken 8 feet bls. For example, copper concentrations increased by 3000% between the 8 and 13 feet bls vadose zone samples at the commercial site while bicarbonate concentrations increased over 6000% between the 8 and 13 feet bls vadose zone samples at the residential site. This indicates that reactions were occurring in the vadose zone that sequestered ions in runoff percolating down to the water table. Concentrations of TDS, Cl, Ca, Na, and bicarbonate in the groundwater increased following infiltration of runoff through the dry wells. For example, the TDS concentration at the commercial site was 332 mg/L prior to a storm event and 407 mg/L afterwards. The bicarbonate concentration was 53.6 mg/L prior to a storm event and 66.0 mg/L following runoff infiltration from that storm event. This suggests that runoff infiltration through dry wells is contributing to the concentrations of particulates and salts in the groundwater.

Oil and grease were consistently detected at low concentrations in runoff, but were mostly non-detect in vadose zone and groundwater samples. The EPA organic priority pollutants were consistently non-detect in runoff, vadose zone, and groundwater samples. This suggests that runoff infiltration through dry wells did not increase the oil and grease and EPA organic priority pollutants concentrations in the groundwater.

Conclusion

The results of this study indicate that reactions in the vadose zone could increase the concentrations of TDS, Cl, Ca, Mg, Na, K, nitrate, and bicarbonate in runoff percolating down to the water table. The

results also suggest that the vadose zone has the capacity to attenuate metals in runoff. Additionally, the results suggest that infiltration through dry wells increased the concentrations of particulates and salts in the groundwater. To reduce the chances of groundwater contamination, the author suggested that pretreatment be used to capture pollutants from runoff before it enters the dry wells.

Additional case study simulations of dry well drainage in the Tucson basin

Bandeem, R.F. 1987. Pima County Transportation and Flood Control District. Tucson, AZ.

Posted at: http://arizona.openrepository.com/arizona/bitstream/10150/306934/1/wrrc_219.pdf

Purpose

This study was conducted to develop criteria for placement of dry wells in different soil conditions to minimize groundwater contamination.

Background

Soil conditions in the Tucson basin vary with highly permeable river channel deposits in some areas and much less permeability in other areas. Many areas in this basin have more than one uniform layer in the subsurface and the degree of permeability can vary. Average depth to the water table is approximately 100 feet below land surface (bls). During the summer, the Tucson area experiences monsoon storms which can produce up to 5,000 cubic feet of stormwater runoff in less than three hours. Dry wells can be used to manage this large amount of stormwater and recharge the aquifer.

As a follow up to previous work, this study used computer models to investigate placement criteria for dry wells which drain into different subsurface conditions, including multiple layers of varying permeability. With the detailed information produced by this study, the placement of dry wells in dynamic subsurface conditions can be incorporated into the design criteria to minimize groundwater contamination.

Methods

This research effort focused on modeling the dispersion of the drainage plume (water that had passed through a dry well) for three scenarios with different subsurface characteristics using UNSAT 2. The input parameters simulated runoff for a five-year, one-hour storm event with an infiltration rate of 0.5 cubic feet per second until a total volume of 5,000 cubic feet had been injected. After 24 hours, a second, identical storm event was simulated to predict further plume migration from the dry well.

Case 1 simulated stormwater from a dry well that entered a uniform layer of highly permeable gravelly-sand material with a water table 100 feet bls. Case 2 simulated percolation into the same highly permeable material, however, this subsurface layer was underlain by a less permeable sandy-clay loam extending from a depth of 30 feet bls to the water table at 100 feet bls. In Case 3 stormwater was modeled to percolate through a dry well into gravelly-sand in the first 30 feet bls, then through a less permeable sandy loam material from 30 feet bls to the water table 100 feet bls.

Results/Discussion

The modeling output provided information on drainage plume distribution, rate of movement, and degree of attenuation between uniform and layered soil conditions. Each case was evaluated throughout the duration of the simulated storm events including the 24 hour period between Storm 1 and 2.

Case 1 simulated a worst case scenario. It had the highest rate of vertical infiltration in the shortest period of time. The drainage plume had the smallest radius (9 feet) and minimal attenuation occurred. The infiltrating stormwater runoff reached the water table 1.5 hours after initiation.

Case 2 was the least likely scenario simulated for the Tucson basin. At 30 feet bls drainage, the vertical movement of water slowed and began migrating laterally along the transition boundary of the subsurface layers before continuing to seep toward the water table. The drainage plume had a much slower velocity than seen in Case 1 and reached the water table between 130 and 150 hours after initiation. The radius of this drainage plume was 27 feet.

Case 3 was a more realistic representation of the Tucson basin and was considered an intermediate case. The drainage water slowed at a depth of 30 feet bls and began lateral migration along the transition boundary of the subsurface but to a lesser degree than Case 2. The drainage plume had a radius of 21.5 feet and reached the water table 5 – 6 hours after initiation.

After a second storm event was simulated for all three cases, flow rates increased because of a higher initial degree of saturation from the previous storm. Drainage plumes radii also increased in Case 2 and 3 but not for Case 1 due to the highly permeable subsurface and fast vertical flow velocity. The greater the soil surface area to which the drainage plume was exposed, the greater the amount of attenuation.

Conclusion

The authors suggested that dry wells should not be placed in areas of uniform, highly permeable soil because drainage water does not have sufficient time for attenuation of pollutants in the vadose zone to occur. A better placement choice for dry wells would be in multi-layered soil with predominant clay materials to maximize attenuation of pollutants in the vadose zone. A sufficient distance between the bottom of the dry well and the water table is 75 feet. This promotes attenuation of pollutants in the drainage water. The author suggested that even under the most favorable subsurface conditions, attenuation of contaminants in the vadose zone may be incomplete.

Urban stormwater injection via dry wells in Tucson, Arizona and its effect on groundwater quality

Olson, K.L. 1987. Master's Thesis, Department of Hydrology and Water Resources, University of Arizona.

Posted at: <http://watershedhealth.org/programsandprojects/was.aspx>

Purpose

The purpose of this project was to determine whether dry wells degraded groundwater quality at study sites in Tucson, Arizona. The study focused on analyzing the composition of sediment collected from sedimentation chambers used for pretreatment of stormwater.

Background

Increased runoff from the paved areas of new developments, combined with inadequate stormwater drainage systems, prompted many communities in Tucson to install dry wells. At the time of the study, 149 dry wells of varying ages were used in residential, commercial and industrial neighborhoods. Groundwater depth was between 100 and 250 feet.

Methods

Dry Well Design

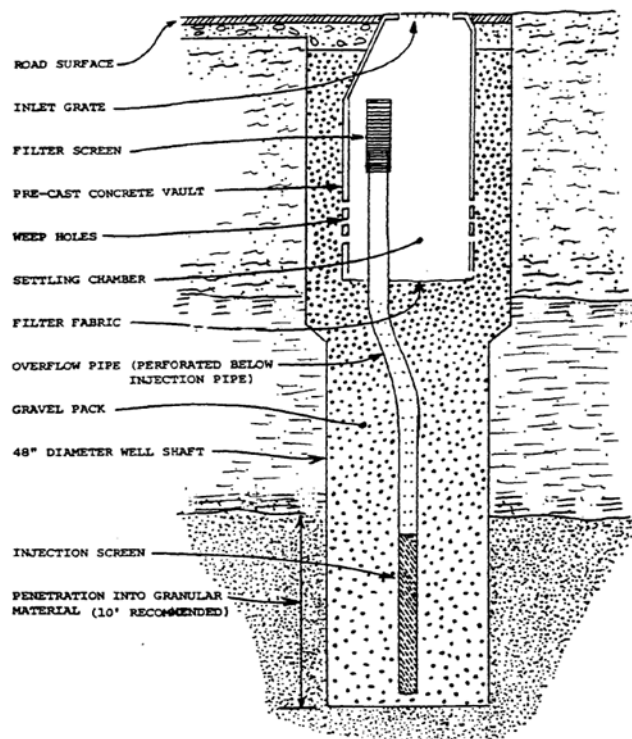


Figure 1. Drawing of typical dry well constructed in Tucson, AZ.

Most dry wells were 4 feet in diameter and 15 – 25 feet deep (Figure 1). Dry wells were set in a 6 foot diameter hole, which allowed for a 12 inch gravel pack in the annular space between the settling chamber wall and the side of the borehole. Below the settling chamber was a gravel pack set in a four-foot diameter borehole. The actual depth of the hole depended on the depth to permeable subsurface sediments.

Dry Well Survey

A survey was conducted to provide information on the number and location of dry wells in the Tucson area. Drilling logs were used to learn vadose zone characteristics near each dry well. Sites that posed the greatest threat to groundwater quality were selected for this study. The selection was based on depth to groundwater, distance to production wells, vadose zone characteristics, presence of potential pollutant sources in the drainage area, and dry well age. Eight dry wells were selected; three residential, three commercial, and two industrial.

Sediment Analysis

Samples were taken from the upper four inches of accumulated sediment in the settling chambers of the eight selected dry well systems. The samples were analyzed for volatile and semi-volatile organic compounds (VOCs and SVOCs), chlorinated pesticides, organochlorine pesticides, PCBs, organophosphates, and metals. Based on the results of these investigations, the site for each land use (residential, commercial, and industrial) with the greatest potential for contaminating groundwater was selected for further study.

Stormwater, Vadose Zone, and Production Well Water Analysis

The dry well at the residential site (apartment complex) was located in a parking area that received runoff from landscaped areas and rooftops. Surface geology (0-10 feet below ground surface (bls)) consists of brown clay followed by a mixture of brown clay and caliche. Subsurface geology (10-70 feet bls) consists of sandy clay, sand, gravel, and some boulders. Groundwater depth was 250 feet. The dry well at the commercial site was located in a garden center. The vadose zone was composed of 75% silt and clay to 25 feet bls. Below that, sand predominated. Groundwater depth was 96 feet. The dry well at the industrial site received stormwater from a parking lot, a rooftop, and a landscaped area. The geology consists of clay to 11 feet bls, decomposed granite between 11-24 feet bls, and sand, gravel, and cobbles between 24-35 feet bls. Groundwater depth was 132 feet.

At the residential sites, stormwater samples were collected at the beginning of the first storm of the season. Stormwater samples at the commercial sites were taken from standing water in the settling chamber while samples at the industrial site were taken from ponded water above the dry well. Vadose zone samples were collected from the industrial site only. Samples were collected every 5 feet below the ground surface for the length of the dry well bore hole (140 feet). A single water sample was collected from a drinking water production well near each dry well site. These production wells were located 150 to 750 feet from the dry wells, depending on the site. It was not specified if these wells were upgradient or downgradient of the dry wells. Stormwater, vadose zone, and production well samples were analyzed for VOCs, SVOCs, polycyclic aromatic hydrocarbons (PAHs), oil and grease, organophosphorus pesticides, organochlorine pesticides, phenols, and phthalate esters.

Results/Discussion

The dry well survey identified 149 dry wells that were in operation in Tucson at the time of this study: 77 in residential areas, 55 in commercial areas, and 17 in industrial areas. Dry well ages were new and up to 10 years old. Pollutant sources common at all sites included oil and grease, metals, pesticides, and fertilizers.

Sediment Analysis

Two of the three residential dry well sites were non-detect for most pollutants. The other residential dry well site had consistently high concentrations of SVOCs; pyrene concentrations were the highest (190-360 mg/kg) followed by benzo[b]fluoranthene concentrations (180-220 mg/kg). This was the residential dry well that was selected for further analysis. Two of the three commercial dry well sites were non-detect for most pollutants. The other commercial dry well site had low but consistently

detectable concentrations of SVOCs. Phthalates were present in the highest concentrations (up to 38 mg/kg). This was the commercial dry well that was chosen for further analysis. The two industrial dry well sites had low but consistently detectable concentrations of SVOCs such as benzo[b]fluoranthene (12-49 mg/kg) and bis(2-ethylhexyl)phthalate concentrations (2.7-42 mg/kg). The dry well with the slightly higher pollutant concentrations was the one selected for further analysis.

In general, the concentrations of pollutants in sediment collected from the settling chambers were higher in older dry wells than newer ones. For example, two of the residential dry wells drained similar asphalt parking areas; the one that was a year older had consistently high concentrations of SVOCs while at the newer dry well, no SVOCs were detected. Additionally, concentrations of pollutants at sites in older, established areas were higher than at sites with newer developments. This suggests that pollutants will accumulate over time in the source area and the settling chamber sediment of the dry well

Polycyclic aromatic hydrocarbons, phthalates, and metals were detected in runoff at sites from all three land uses (Table 1).

Table 1. Pollutants in runoff exceeding Maximum Contaminant Levels (MCLs) and/or Health Based Advisory Levels. ^a = Drinking Water Equivalent Level (DWEL), ^p = Public Health Goal

ND = Not Detected

Pollutant	Land Use			MCL (mg/L)	Health Based Advisory Level (mg/L)
	Residential (mg/L)	Commercial (mg/L)	Industrial (mg/L)		
Benzo[a]pyrene	0.220	ND	ND	0.0002	0.000007 ^p
Anthracene	21.00	ND	ND	-	10 ^a
Cadmium	0.010	ND	ND	0.005	0.00004 ^p
Chromium	4.2	0.027	ND	0.1	0.01
Lead	0.10	ND	ND	0.015	0.0002 ^p
Mercury	0.003	ND	0.0014	0.002	0.0012 ^p
Nickel	1.5	-	ND	0.1	0.012 ^p
Thallium	0.22	-	ND	0.002	0.0001 ^p

Note: Some contaminants such as benzo[b]fluoranthene and benzo[k]fluoranthene were detected at elevated concentrations (> 0.2 mg/L) in the runoff, but they were not included in Table 1 because they are not currently listed in regulation or health based advisory records.

Minor amounts of cadmium, lead, nickel, copper, and silver were detected throughout the sediment collected from vadose zone of the industrial site. Of these, cadmium and lead were the only metals that exceeded the MCL with concentrations of 0.13 mg/L and 0.56 mg/L, respectively. Pollutants were not detected in the water in any of the production wells with the exception of zinc, which was detected at

the commercial site at a concentration 33 times less than the DWEL. This finding suggested that the vadose zone was attenuating the metals and that runoff infiltration through dry wells had not degraded groundwater quality.

Conclusion

This study showed that organic pollutants, especially SVOCs, accumulated in the sediment in the settling chambers of dry wells over time. It should be noted that the laboratory holding time was exceeded for a few contaminants during dry well sediment testing, so the concentrations of contaminants may have been greater than reported. The results also indicated that metals were attenuated in the vadose zone. Additionally, the results indicated that runoff infiltration had not degraded groundwater quality because no contaminants, except for trace amounts of zinc, were detected in water pumped from public supply wells located near dry wells.

The author recommended that further long-term studies were needed that focused on groundwater monitoring rather than sediment monitoring. It was also suggested that dry wells should be prohibited in areas that receive drainage from sites with heavy chemical use. A reduction in pollutant sources was another alternative that would reduce the risk of groundwater contamination.

OEHHA Note: References to MCLs were added by OEHHA. MCLs and other health advisory reference values refer to California values for comparative purposes.

Case study simulations of drywell drainage in the Tucson basin

Bandeen, R.F. 1984. Pima County Transportation and Flood Control District. Tucson, AZ. Posted at: http://arizona.openrepository.com/arizona/bitstream/10150/306934/1/wrrc_219.pdf

Purpose

The objective of this study was to establish design placement criteria for dry wells to ensure sufficient distance from nearby water supply wells, especially in situations where there is a near-impermeable clay layer in the subsurface that promotes lateral movement of potentially contaminated runoff. Mindful placement of new dry wells would prevent laterally moving perched water from reaching a well borehole and causing groundwater contamination.

Background

Tucson commonly uses dry wells to manage its stormwater runoff. Many of these wells terminate in caliche layers, a rock-like material formed by the mixing of gravelly sand with calcium carbonate-rich groundwater. Water draining from a dry well may "perch" temporarily above a layer of caliche, travel laterally to a nearby water supply well shaft, and leak through the permeable gravel pack or disturbed zone surrounding the well's casing, thereby increasing the risk of groundwater contamination.

Methods

This study simulated dry well drainage plumes under typical subsurface conditions in Tucson with the computer program UNSAT 2. Using field data, four case studies were modeled to track movement and create a drainage plume profile of the saturated zone surrounding a hypothetical dry well at the University of Arizona. The four case studies simulated by the computer were as follows:

- Two dry wells were subjected to one hour of 100 year flood conditions; Case 1a had no vertical leakage due to impermeable subsurface conditions while Case 1b had vertical leakage and finite permeability in the subsurface. The expected total runoff from a one acre paved area at this site was 9644 cubic feet.
- Two dry wells were subjected to steady drainage of stored runoff over extended periods of time. Case 2b had vertical leakage in the subsurface while Case 2a did not. Both Case 2a and 2b captured a steady flow of 0.5 cubic feet per second for more than 24 hours.

The program used a two-dimensional grid of flow cells to represent the permeability of the subsurface. The grid lines intersected at points called nodes. The influent to the system was simulated by assigning a hydraulic head value to each of the nodes. Flow predictions were dependent on model input parameters that depicted the hydraulic properties of the subsurface. The input parameters included saturated hydraulic conductivity (K_s); a ratio of relative hydraulic conductivity (K_r), with K_s ranging from 0 to 1, and its relationship with water content in the soil (θ); and a relationship between the amount of suction, measured as a negative pressure head ($-\psi$) which corresponded to volumetric water content. Lastly, soil hydraulic properties were determined. This analysis resulted in a soil moisture retention curve. Indirect methods were used to obtain the hydraulic properties for this material since there were no physical samples of the soil available.

Dry Well Design

The modelling effort was based on a dry well design that was identical to one on site at the University of Arizona's Water Research Lab. It featured a 4 foot diameter borehole that extended 23.5 feet below land surface (bls). The dry well chamber contained gravel and was perforated up to a level of about 8.5 feet bls.

Results/Discussion

In Case 1a, the drainage plume extended approximately 40 feet radially from the center of the dry well at the time drainage ceased. After all runoff passed through the dry well, the plume migrated an additional 40 feet laterally. Maximum lateral migration of the plume from a 100 year storm event was conservatively estimated to be 100 feet.

In Case 1b, the plume migrated laterally approximately 25 feet from the dry well and was not likely to migrate much further after the influx of stormwater stopped. The effects of vertical drainage in this case sharply reduced the extent of lateral migration. Maximum lateral migration of the drainage plume from a 100 year event would be roughly 50 feet.

Progressive flow profiles for the drainage plume in Case 2a showed significant lateral migration over a 27 hour period, ultimately extending laterally more than 680 feet. This exceeded the boundary of the simulation grid of the model. Data collected after that was deemed unusable.

Due to limited computer storage capabilities at the time of the study, the simulation of Case 2b was not performed. The authors noted that it would have given a more realistic estimate of lateral migration from a dry well under conditions of long-term drainage where vertical drainage occurs.

Conclusion

The risk of groundwater pollution from lateral migration of stormwater infiltrated through dry wells that leaks into cracks in water well casing can be avoided by placing all dry wells a minimum of 100 feet away from water supply wells. Depending on the volume of water to be disposed of, the placement of dry wells may vary. The authors noted that results assume the existence of a perched aquifer, and thereby represent the worst case scenario. Where impermeable stratum is absent, lateral migration will be considerably less.

Articles of Related Interest

Artificial recharge of groundwater: hydrogeology and engineering

Bouwer, Herman. 2002. Hydrogeology Journal: 121 — 142.

Posted at:

http://leg.mt.gov/content/committees/interim/2005_2006/environmental_quality_council/meetings/minutes/eqc09112006_ex18.pdf

Summary

The artificial recharge and storage of water in the ground provides benefits including elimination of evaporation of storing water on the surface and natural geopurification as water infiltrates from the recharge device to the water table. The author reviews a number of key issues associated with using a variety of different types of recharge systems including dry well.

Recharge systems such as vadose-zone wells (i.e. dry wells) are vulnerable to clogging. The well walls may be clogged by accumulation of inorganic and organic suspended solids, and the downward movement of fine particles can form a thin clogging layer at some depth. Since it is expensive and cumbersome to pump and clean dry wells to clear clogging layers, removing fine particles before recharging water enters the well is important. If a clogging layer does form, the layer becomes the limiting factor for infiltration. The material below the layer becomes unsaturated, and its hydraulic conductivity (ease with which water passes through a substance's pore spaces) is then equal to the infiltration rate, which is dependent on gravity.

The design of any recharge system should also consider the hydrogeological characteristics of the installation to ensure sufficient infiltration capacity. The hydraulic conductivity (K) is a key factor needed to estimate infiltration rate. K varies with soil type as follows (m/day): clay soils <0.1, loams 0.2, sandy loams 0.3, loamy sands 0.5, fine sands 1, medium sands 5, and coarse sands >10. The actual infiltration rate can be estimated with the Green-and-Ampt equation for flooded soils: $VI = K((Hw + Lf - hwe)/Lf)$, where VI is the infiltration rate, K is the hydraulic conductivity of wetted zone, Hw is the water depth above soil, Lf is the depth of the wetting front, and hwe is the capillary suction of negative pressure head at the wetting front.

Another factor to consider is the possible formation of perched mounding. When infiltrating water comes in contact with layers of low permeable material, such as clay, the “perched” water above that layer will rise until sufficient head (pressure) is built to allow the water to infiltrate through the layer at the rate it infiltrates through the substrate above the less permeable layer. This mounding can significantly retard downward infiltration of stormwater. The author discusses in detail the mounding phenomenon and factors affecting it.

The author identifies areas in need of additional research: optimal design for well capacity, clogging control including pre-treatment, useful life, and long term costs per unit water.

Estimation of groundwater recharge from precipitations, runoff into drywells, and on-site waste-disposal systems in the Portland basin, Oregon and Washington

Snyder, D.T., Morgan, D.S., and T.S. McGrath. 1994. USGS Water Resources Investigations Report 92-4010: 1—24.

Posted at: <http://pubs.usgs.gov/wri/1992/4010/report.pdf>

Purpose

The purpose of this study was to quantify and compare the annual recharge potential of rain and stormwater runoff through dry wells and septic tanks in the Portland Basin.

Background

The Portland Basin is a 1,310 square mile area in northwestern Oregon and southwestern Washington that includes the City of Portland. It has a Mediterranean climate and receives 42 inches of rain annually. The major land uses in the basin are forests (50%), urbanized areas (26%), and agriculture (17%).

Methods

A modified version of the Deep Percolation Model for Estimating Groundwater Recharge (Bauer and Vaccarao, 1987), which measures the amount of recharge from precipitation based on soil moisture, soil evaporation, plant transpiration, surface-water runoff, snow cover and evaporation of precipitation, was used in three representative sub-basins of the Portland Basin. The Portland Basin had 5,700 shallow, large diameter dry wells in the urban area (UA) in Multnomah County and Clark County. A grid unit was superimposed on a map of the UA, with each grid cell being about 1 square mile. It was assumed that all runoff in each grid cell would flow toward the dry wells. The amount of runoff that went into the dry wells was calculated for each grid cell by this formula:

Runoff into dry wells = precipitation that falls on impervious surfaces – (surface detention + evaporation)

Note: Surface detention=precipitation that fell on and was trapped by impervious surfaces.

Precipitation levels were obtained from the North Willamette Agricultural Experiment Station. Impervious area was estimated from the USGS 1:250,000-scale land use/land cover digital data map. Evaporation levels were determined using a bucket model, where the evaporation rate of water in a bucket was observed in the study environment. It was assumed that the runoff that went into the dry wells would eventually recharge the aquifer. Recharge volume was computed for each grid cell and then aggregated and adjusted for the total area of the UA and the Portland Basin.

Results

The analysis showed that about 75% of precipitation falling on impervious surfaces of the Portland Basin became runoff that went into dry wells. Precipitation contributed 21 inches/year to groundwater recharge. In urbanized areas, dry wells contributed 38% of total groundwater aquifer recharge and septic systems contributed 17%.

Conclusion

The results of this study suggested that runoff infiltration through dry wells has the potential to make significant contributions to recharge in urban areas.

OEHHA Note: Many assumptions were made throughout this study. For example, it was assumed that all runoff in a grid cell would flow toward dry wells and not to more permeable areas. Therefore, the results had a high degree of variability. Further, no analysis of total recharge volume was provided.

Bibliography

Bauer, H.H., and Vaccaro, J.J., 1987. Documentation of a deep percolation model for estimating ground-water recharge: U.S. Geological Survey Open-File Report 86-536, 180 p.

Maintenance of stormwater BMPs in four Maryland Counties: a status report

Lindsey, G., Roberts, L. and W. Page. 1992. *Journal of Soil and Water Conservation*. Vol. 47:417-422

Summary

This report presented the findings of the field inspection of 258 stormwater Best Management Practices (BMPs) in Maryland. The types of facilities inspected include detention basins, infiltration basins and trenches, dry wells, underground storage facilities, and vegetated swales. Dry wells are defined in this study as aggregate-filled excavations that store water in the void space between stones until infiltration occurs. Each system involved in the study was evaluated to answer the following questions: Is the facility working as designed? Is the facility storing water or providing quantity controls as designed? Is the facility producing water quality benefits? What type of maintenance is needed? After the conclusion of the study, statistical tests were performed in order to uncover any inspector or county bias, if they existed. Bias was not found to be a factor in the determination of a facility's status.

Of the 258 facilities inspected, 22 were dry well sites (9%). Of the 22 dry wells, 17 were functioning as designed (77%), 17 were performing quantity control as designed, and 20 were improving groundwater quality (91%), which was the highest percentage out of the eight categories of facilities (dry basins, wet detention basins, infiltration basins, infiltration trenches, dry wells, underground storage, vegetated swales, and an "other" category) that were reviewed. Only six of the dry wells needed maintenance (27%), the lowest percentage in all of the categories. In terms of performance criteria compliance, none of the dry wells experienced structural failures, only three (14%) experienced slow infiltration, clogging of the facility only occurred at four wells (18%), and only 4 experienced excessive sediment or debris, again the lowest percentage of the eight categories. In terms of maintenance criteria, dry wells performed best in 5 of the 6 vegetative conditions requirements, and 3 of the 7 sediment conditions requirements. Dry wells had the smallest amount of sediment entering any of the facilities (6 wells or 27%).

The results of this review showed that after a few years almost one-third of the BMPs were not functioning as designed. Sedimentation was the most widespread problem at all of the BMP sites, occurring at approximately half of the 258 facilities. Sediment removal was the only enforcement action warranted for infiltration facilities, such as dry wells. The need for maintenance was greatest for infiltration basins and dry ponds, and as previously stated, lowest for dry wells. Dry wells performed well in comparison to other BMP facilities, and their perceived benefits include pollution control, mitigation of temperature effects, groundwater recharge, and maintenance of base flow.