DESIGN TOOL USER'S GUIDE

HRX Well Design, Cost, and Sustainability Tool and Analysis

Demonstration and Validation of the Horizontal Reactive Media Treatment Well (HRX Well®) for Managing Contaminant Plumes in Complex Geologic Environments

ESTCP Project ER-201631

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The HRX Well® design tool was developed to provide preliminary site design estimates to practitioners considering implementation of the HRX Well. Many HRX Well configurations are possible, but the applicability of any design is subject to site-specific factors. The tool allows the user to optimize the design based on user-provided values and using the equations described in Divine et al. (2018). Supplemental literature values can also be used as inputs to support high-level estimations. The tool predicts well length, capture width, and the number of wells required to meet target treatment goals. In addition, the associated costs and sustainability implications are calculated, which can further inform design selection. For many sites, a site-specific numerical flow and transport model may be useful for final design, as well as predicting and assessing HRX Well performance.

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TABLE OF CONTENTS

Figures

Tables

Attachments

1 INTRODUCTION

The HRX Well® design tool was developed to provide preliminary site design estimates to practitioners considering implementation of the HRX Well. Many HRX Well configurations are possible, but the applicability of any design is subject to site-specific factors. The tool allows the user to optimize the design based on user-provided values and using the equations described in Divine et al. (2018). Supplemental literature values can also be used as inputs to support high-level estimations. The tool predicts well length, capture width, and the number of wells required to meet target treatment goals. In addition, the associated costs and sustainability implications are calculated, which can further inform design selection. For many sites, a site-specific numerical flow and transport model may be useful for final design, as well as predicting and assessing HRX Well performance.

The tool can be used for a holistic evaluation of known or estimated site parameters and the resulting HRX Well configuration. Additional iterations using the tool can be completed to improve the design. A Tool Overview tab provides background, assumptions, and instructions. The User Input tab allows values to be entered or selected, depending on the parameter. Initial results are calculated in a locked HRX Well calculations tab, the Cartridge Calculations tab, the Cost tab, and the Sustainability tab, and the results are given in the Summary tab. The user can enter a pump rate or select mix-in media values to further specify capture width. The adjusted capture width and associated results will also be displayed under the Summary tab. The primary tool outputs are the required number of wells, well diameter, cartridges, well length, and the retention time required. The tool incorporates several user-specified inputs to minimize cost and maximize effective treatment. In addition, both cost analysis and sustainability analysis are included.

The design tool includes cost and sustainability assessments based on the materials used and drilling time. Data were obtained from several sources and references and web links are provided in the Lookup Tables and Assumed Values tabs in the design tool. These references can easily be updated with specific values by replacing the data in the cell, though the value should be converted to units shown.

Costs for mobilization, directional drilling, well assembly, development, sealing, cartridges, casing, and well ends and vaults were provided by Michael Lubrecht at Directed Technologies Drilling-Ellingson. These costs were determined for the Vandenberg Air Force Base installation and the resulting costs in the tool for a specific site should be taken as estimates. A formal quote should be obtained from the drilling company. An option to use polyvinyl chloride (PVC) casing was included on the User Inputs tab and the associated costs were determined from online suppliers: Flex Pipe, PVC Pipe Supply Store, and PVC Fittings Online. Reactive media costs were similarly determined from available costs at home water treatment supply stores, chemical supply companies, cost reports for treatment systems, and miscellaneous online retailers. These costs therefore represent estimates and the user should obtain quotes from reputable suppliers specific to their sites. The option is provided to add known cost data for media and this option is recommended.

Sustainability data were also obtained from multiple sources. A literature search demonstrated that the metrics intended to be included in the tool were not all available from the same reference for the same material. For example, granular activated carbon CO_2 equivalent emissions may be available from one reference, but not PM_{10} emissions. Furthermore, the literature reference may not have provided enough information to ensure each metric was comparable for the given material. Therefore, the SiteWise program (version 3.2) was used (where cited) in the tool as a baseline and was supported by additional references. All references and links are in the Lookup Tables tab. The results from the sustainability tab provide a general sustainability assessment and are useful to compare between design iterations. The results should not be taken as a complete lifecycle inventory analysis such as those obtained from a software such as GaBi.

Table 1. Cost References Used in the Design Tool

Item	Reference
Mobilization costs Directional drilling HRX Well assembly and installation HRX Well development HRX Well sealing Cartridge construction + supplies 12 in St. steel well screen 12 in carbon steel casing HRX Well ends, vaults	Michael Lubrecht (DTD-Ellingson), 2019, personal communication.
Activated carbon	Water softener parts (webpage): https://www.softenerparts.com/Carbon
Zeolite	EnviroSupply (webpage) https://envirosupply.net/products/zeolite
Persulfate	Rosansky and Dindal. (2010). Cost and Performance Report for Persulfate Treatability Studies.
Zero valent iron	Connelly Iron Products. (2018). Product Quote.

Table 2. Sustainability References Used in the Design Tool

Material	Reference
Baseline references	NAVFAC, 2016. SiteWise™ Tool - V3.1. Developed by the Department of the Navy, Army Corps of Engineers, & Battelle Link: https://www.navfac.navy.mil/navfac_worldwide/specialty_centers/exwc/products_and_services/ev/erb/gsr.html#tools
Bentonite	Hammond and Jones. (2008). Embodied energy and carbon in construction materials. Proceedings of the Institution of Civil Engineers. 161:2, 87-98. https://researchportal.bath.ac.uk/en/publications/embodied-energy-and-carbon-in-construction-materials

Material	Reference
Portland cement	Song, D., Yang, J., Chen, B., Hayat, T., Alsaedi, A. (2016). Life-cycle environmental impact analysis of a typical cement production chain. Applied Energy, 164:15, 916:923. https://www.sciencedirect.com/science/article/pii/S0306261915010715
PVC	Baitz, M., Kreibig, J., Byrne, E., Makishi, C., Kupfer, T., Frees, N., Bey, N., Hansen, M.S., Hansen, A., Bosch, T., Borghi, V., Watson, J.., Miranda., M. (2015). Lifecycle Assessment of PVC and of principle competing materials. European Commission. https://ec.europa.eu/environment/waste/studies/pdf/pvc-final_report_lca.pdf
Stainless steel	Finkbeiner, M., Dowdell, D., Inaba, A., Young, S. (2011). Methodology Report: Lifecycle inventory for steel products. World Steel Association. https://www.worldsteel.org/en/dam/jcr:6a222ba2-e35a-4126-83ab-5ae5a79e6e46/LCA+Methodology+Report.pdf
Activated carbon	Bayer, P., Heuer, E., Karl, U., Finkel, M. (2005). Economic and ecological comparisons of granular activated carbon (GAC) adsorber refill strategies. Water Research. 39, 1719-1728. https://www.ncbi.nlm.nih.gov/pubmed/15899270
Diesel	Office of Transportation and Air Quality. (2016). Nonroad Compression-Ignition Engines: Exhaust Emission Standards. United States EPA. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100OA05.pdf

2 USER INSTRUCTIONS

The following can be used to guide the user through the design tool. The instructions do not include an overview of groundwater hydrology concepts as the tool is intended for use by experienced remediation professionals.

Step One: Review Tool Guidance

The first tab in the design tool (Tool Overview) provides an introduction, necessary definitions and assumptions, and instructions which are also provided below:

HRX Well Design Tool Overview and Instructions

The HRX Well tool has been produced to assist in system design. The tool uses values from literature and user inputs to estimate number and size of wells and the associated costs for site-specific conditions. The current and future design tool versions will be available at:

https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Persistent-Contamination/ER-201631

Notes and Assumptions

1. Treatment media treatability testing is not required to make use of the tool; however, it may be advantageous or necessary for some applications. Attempts have been made to provide useful and valid literature-based treatment media values, but they should only be taken as general information. These generalizations apply to hydraulic conductivity, reaction rate, and cost.

2. Method used to determine reference values available in the tool:

A. Determine contaminant categories and general media categories.

B. Pick a representative contaminant for the contaminant category.

C. Literature search for hydraulic conductivity for each media.

D. Literature search for direct values or information to calculate reaction rate with media for representative contaminant.

3. Key input values: Site hydraulic conductivity, aquifer thickness, treatment media hydraulic conductivity, reaction/adsorption rate constant, and treatment goals and the contaminants included.

4. Key output values: Number of HRX Wells, HRX Well dimensions, pumping rate if required.

The tool has been designed to allow the user to enter and or select specific known values which are used to calculate the key output values as well as other information. These values are reported in the Summary tab.

Active pump rate: This value should be determined from pumping tests and supplied by the user.

5. For users interested in further refining values to meet project requirements, a pump rate can be added or a mix-in media (explained below).

6. Cost data include values for HRX Well materials and installation provided for 10-inch diameter HRX Wells. In the case where a smaller or larger diameter is used the costs should be considered general and not be interpreted as the final project cost. Please see Assumed Values tab for more information.

7. Treatment and cartridge length. Treatment length is defined as the length of media, per cartridge diameter, available for treatment. Cartridge length is the length of the cartridge containing media as well as empty fittings on either end. The cartridge length is equal to the media length plus 25% of the media length to account for space for fittings.

General Instructions

1. White cells are for calculations and are locked. Cells highlighted in **green** are for value selection from a list. In some cases, parameter value selection is not required if values are entered in adjacent cells. In these cases, one set of cells must remain blank. For example, under User Inputs tab, there is an option (in **orange**) to enter contaminant and media values and below that in green to select media values from the literature. Calculations in other tabs using these values require one set of cells (orange or green) to be blank. Blank cells

highlighted in **blue** indicate the rows requiring information to calculate capture width, and nothing else.

2. Under the User Inputs tab note that a simple calculator is available to convert hydraulic conductivity from ft/d to cm/s and concentration from molar units to ug/L in O and P rows 5-9. Additional conversion factors are available immediately below:

A. Enter site name, location, and the contaminant(s) present. The information is transferred to the Summary tab for organizational purposes.

B. Enter Contaminant information and treatment goals. If more than one contaminant is present:

Enter individual contaminant name, initial concentration, target concentration or percent reduction, and rate constant for one contaminant at a time.

→ Record the treatment length (M49, User Inputs) for each contaminant.

→ Use the information associated with the longest calculated treatment length to determine HRX Well length in later steps. Note: If two contaminants are highly dissimilar and or require different media the above steps may not be appropriate.

C. Enter site hydraulic conductivity, site and well hydraulic gradient, and aquifer thickness. Note that the tool uses hydraulic conductivity in cm/s. Transmissivity is calculated automatically based on input values.

D. Enter treatment media information in row 32 (row 31 notes each component required) *or:*

E. Select treatment media information in row 35. A small selection of values from the literature are provided and categorized by contaminant class. Values may not be representative for your site. The values are also available in the Lookup Tables tab and can be manually entered in row 32 in other combinations.

F. If media capacity information is available enter it in M37. Capacity is not a required input but will update both cost and sustainability data.

→ If capacity is not available and K_d is, enter the K_d value which will be used with initial concentration to approximate capacity.

G. In M41 select "Active" for sites where K_{media} is greater than 5 ft/d. Otherwise, select "Passive".

→ If "Active" was selected, enter a pump rate in M42. The pump rate will override the media conductivity values entered and be used in the capture width calculation.

H. Select HRX Well diameter from the drop-down menu in M48. Note that the tool will assume the cartridge diameter is 2 inches less than the HRX Well diameter.

I. Select carbon steel or PVC well casing from M55. The selection will be used to determine the casing cost.

J. Enter known or estimated cost per kilogram of treatment media used.

3. View results of 1. in the Summary tab in H3-28.

A. Review capture width, number of HRX Wells, and the HRX Well retention time versus the retention time required based on the contaminant information entered. B. If capture width is not satisfactory consider: →Increasing HRX Well diameter →Adding a pump rate in User Inputs M42 →Selecting a mix-in media and entering the percent of media to use →Determining if there is flexibility in treatment goals or treatment media (hydraulic conductivity) used 4. Change flexible parameters from Step 2 and or add a small pump or mix-in media in the User Inputs tab. 5. View results from using mix-in media or adding a pump in the Summary tab A. Repeat the above steps to continue refining the design.

Step 2: Gather Input Information

The tool requires a series of values to be supplied and or selected by the user. **Table 3** gives the required values and can be used to organize information prior to using the tool. **Table 4** provides the selection values where these are required. Estimated values may be used in the design tool but values from site investigations and treatability testing are ideal for high level estimation.

Table 3. Required Information for the Design Tool

General Site Info	
Site Name	
Site Location	
Known contaminant:	
Contaminant information	
Target treatment width (feet [ft])	
Target treatment depth (ft)	
Initial contaminant concentration (micrograms per liter [µg/L])	
Enter treatment media porosity n	
Treatment goals	
Percent reduction (%)	
or	
Concentration (µg/L)	
Enter $k_{contaminant}$ (min^{-1})	
Contaminant half-life (days)	

Site information	
Enter site hydraulic conductivity K (centimeters per second [cm/s]; feet per day [ft/d])	
Enter site hydraulic gradient i	
Enter aquifer thickness b_a (ft)	
Enter site transmissivity T (square centimeters per second [cm^2/s]; square feet per day [ft^2/d])	
HRX Well hydraulic gradient	
Enter or select contaminant and media values	
Enter contaminant name	
Enter media type	
Enter media hydraulic conductivity (cm/s)	
Select	See Tables 4A-B
Select Media	See Tables 4A-B
Media hydraulic conductivity (cm/s)	
HRX Well parameters	
Select HRX Well diameter (inches [in])	
If the site will require pumps enter the rate (gallons per minute [gpm])	
Drill time (hours)	
Miscellaneous	
Enter cost per kilograms (kg) of media	

Table 4A and B. Summary of Available Selections for Table 3

(These values can also be found under Lookup Tables and Assumed Values tabs in the design tool.)

A

Well Diameters (in)
6
8
10
12
14
16
18

B

Media Name	Hydraulic Conductivity (cm/s)	Reaction Rate Constant (min-1)	Hydraulic conductivity Reference	Reaction Rate Constant Reference
gZVI-Radionuclide	0.015625	4.00E-07	GMA/coarse	Bronstein 2005/Uranium
Phosphates-Radionuclide	0.0225	9.20E-04	Xing 2016/Apatite	Saxena et al 2006/Uranium on rock phosphate
Zeolite-Radionuclides	0.002	2.70E-04	Oren et al (2013)	Kilincarslan and Akyil 2005, Uranium on clinoptilite (fine, low K) zeolite
gZVI-Metals	0.015625	0.003033333	GMA/coarse	Bruzzoniti et al 2014/gZVI pH 5
Phosphates-Metals	0.0225	1.70E-02	Xing 2016/Apatite	Ryan 1993 /Pb on Hydroxyapatite
gZVI-VOCs	0.015625	3.00E-03	GMA/coarse	Baciocchi et al 2003/TCE on gZVI
Organoclays-VOCs	6.90E-02	ND	Benson et al 2014	
Granular oxidants-VOCs	ND	1.00E-02	ND	Yan et al 2015/NaS2O8 only for TCE
GAC-PFAS	1	4.00E-07	Bortone et al (2013)	Liu 2019/Calgon F400 GAC
Ion exchange resin-PFAS	0.330625	ND	DOWEX UPCOREMono A-500	ND
gZVI-PFAS	0.015625	ND	GMA/coarse	ND

Step 3: Enter Values in Design Tool

Preliminary calculations only require **Table 3** to be completed (found under the User Inputs tab). The preliminary output values can be found in the top table (Summary tab) shown in **Table 5**.

Table 5. Values Included in a Summary of Initial Outputs

Outputs from User Input tab	Result
HRX Well average capture width (ft)	
Number of HRX Wells	
HRX Well HRT (days)	
Contaminant HRT required (days)	
HRX Well length (ft)	
Site is active or passive	
Active pumping rate (gpm)	
Cartridge length (ft)	
Number of cartridges	
Total capital cost per HRX Well (USD)	
Initial cost of reaction media (USD)	
Annual media changeout cost (USD)	
Consumables total (kg CO_2 e)	
Consumables total (g NOx)	

Outputs from User Input tab	Result
Consumables total (g SOx)	
Consumables total (g PM10)	
Consumables total (MJ)	
Consumables total (MWH)	
Annual media changeouts (kg CO_2 e)	
Drilling total (kg CO_2 e)	
Drilling total (g NOx)	
Drilling total (g SOx)	
Drilling total (g PM10)	
Drilling total (MJ)	
Drilling total (MWH)	
Drilling for changeouts kg CO_2 e)	

These values are calculated under the HRX Well Calculations tab, the Cartridge Calculations tab, the Sustainability tab, and the Cost tab. Additional values calculated can be viewed under the respective tabs but the tabs are locked to prevent alterations to the equations used.

Step 4: Optimization of Inputs

The optimization step is optional and was configured to increase capture width and reduce the number of HRX Wells. The subsequent outcomes include reducing costs and increasing installation efficiency. It is assumed that many site characteristics (i.e. aquifer thickness and hydraulic conductivity) cannot be altered for the sake of optimization. Therefore, a simplified table is provided in **Table 6**.

Table 6. Parameters That Can Be Adjusted to Increase Capture Width

Design Optimization	Value
Enter or select treatment media	Select from Tables 4A-B
Enter media hydraulic conductivity (cm/s)[A]	
Enter reaction rate constant[A]	
Select mix-in media	
Enter mix-in media percent	
Update HRX Well diameter	
Enter a pump rate in M44	

[A] Enter if not selected along with contaminant and treatment media

The same values given in **Table 4A-B** can be selected here. There are two options to improve capture width or increase retention time. First, by adjusting hydraulic conductivity with a non-reactive mix-in media (described below) the capture width can be adjusted. Second, by entering a pump rate in M44 under the User Inputs tab.

Selections of mix-in media (e.g., coarse grained silica sand) are provided to adjust hydraulic conductivity (**Table 7**). Mix-in media was included in the design tool in order to optimize hydraulic conductivity (and related parameters) in the cartridges. The non-reactive mix-in media are useful when hydraulic conductivity is too high or too low for the treatment media. In these scenarios, the retention time determined from reaction rate constants may not be achieved. Changing the hydraulic conductivity in the cartridge is one method of specifying the cartridge retention time.

Table 7. Mix-in Media Available for In-Well Hydraulic Conductivity Adjustments

Mix-in media	Hydraulic conducitivity (cm/s)	Porosity
Gravel	3.00E+00	0.2
Coarse sand	6.00E-01	0.25
Fine sand	2.00E-06	0.3

The results of the optimization are given in **Table 8** (Summary tab).

Table 8. Summary of Optimization Activities

Updated Results Using Mix-in Media or a Pump Outputs from User Inputs tab	Result
HRX Well average capture width (ft)	
Number of HRX Wells	
HRX Well HRT (days)	
HRX Well length (ft)	
Active pumping (gpm)	
Cartridge length (ft)	
Number of cartridges	
Total capital cost (USD)	
Total cost of reaction media (USD)	
Consumables total (kg CO_2 e)	
Consumables total (g NOx)	
Consumables total (g SOx)	
Consumables total (g PM10)	
Consumables total (MJ)	
Consumables total (MWH)	
Drilling total (kg CO_2 e)	
Drilling total (g NOx)	
Drilling total (g SOx)	
Drilling total (g PM10)	

Updated Results Using Mix-in Media or a Pump Outputs from User Inputs tab	Result
Drilling total (MJ)	
Drilling total (MWH)	
Cartridge length (ft)	**Number for HRX Well length**
5	
10	

Step Six: Assessment of Results

Results of the tool should be reviewed and the practicality of recommendations considered. Use of the tool does not guarantee successful installation, complete project costs, or desired treatment outcomes. Thorough site investigations and treatability testing are typically necessary to have successful remediation outcomes. It is important to note that the tool currently does not have restrictions on most values, therefore common sense should be used when reviewing the summary. For example, if the number of HRX Wells exceeds site or budget capacity, additional design iterations should be completed to reduce the number of HRX Wells. If multiple HRX Wells will be applied at the site, the configuration is shown in **Figure 1**. HRX Wells be oriented parallel to the direction of groundwater flow but site-specific orientations may be required.

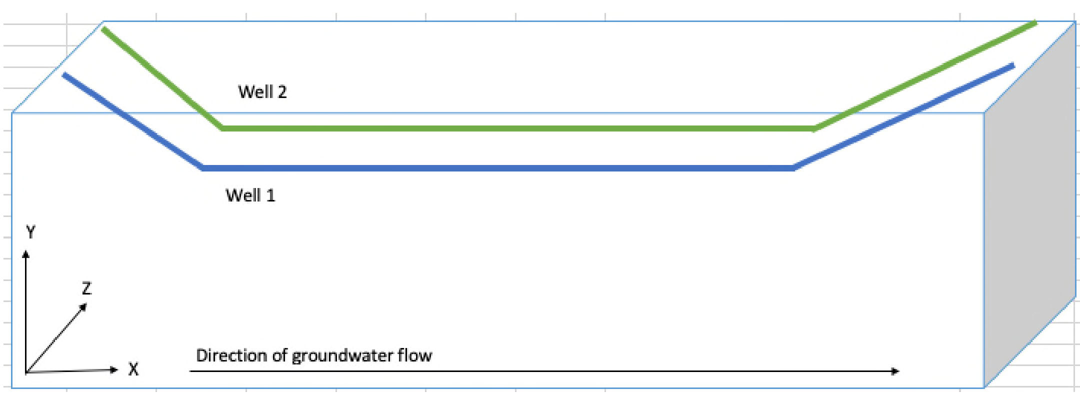


Figure 1. Orientation of Multiple HRX Wells Relative to Direction of Groundwater Flow

3 DESIGN TOOL APPLICATION EXAMPLES

The HRX Well design tool was demonstrated for four Department of Defense (DoD) sites: Vandenberg Air Force Base (VAFB) Site 3 where the field demonstration was completed and three additional DoD sites where HRX Wells are being considered (referred to here as DoD-A, DoD-B, and DoD-C). Known and estimated values were used in the tool for the latter three sites and additional iterations were completed to achieve reasonable capture widths. The following variables shown in each table are defined:

K_{rxn} -Pseudo first-order rate constant

K_A -Aquifer hydraulic conductivity

K_W -Media hydraulic conductivity

n -Media porosity

b_A -Aquifer thickness

i_A -Aquifer hydraulic gradient

i_W -Well hydraulic gradient

The tool was first demonstrated using the same inputs described in the previous modeling component for VAFB. **Table 9** provides the inputs and results for the design.

Table 9. HRX Well Design Tool for the VAFB Site

Site Name: Vandenburg						
Input Parameter	Value	Units		Output Parameter	Value	Units
Target treatment width	150	ft		Treatment width	44	ft
Target treatment depth	20	ft		Number of wells	4	
k_{rxn}	0.001	min^{-1}		Well length total	425	ft
Required retention time	5	days		Treatment length	64	ft
Actual retention time	12.7	days		Cost	272736	$
Treatment magnitude	3.2	OoM				
K_A	0.35	ft/d				
K_W	196	ft/d				
n	0.3					
b_A	7	ft				
i_A	0.007					
i_W	0.007					
Well diameter	12	in				
Cartridge diameter	10	in				
Active or passive	passive					
Active rate	NA	gpm				

The results in **Table 9** show that a 12-inch diameter well with media hydraulic conductivity of 196 ft/d will exhibit a capture and treatment zone width of 44 ft. The capital cost to build and install the well was $275,742. These costs do not include the consulting or oversight-related costs. Installing three wells to cover the target 150 ft plume costs $872,226 which is less than capital costs associated with several other comparable remedial technologies. It is important to note that while the well diameter is 12 inches, the cartridge diameter is approximately 2 inches less. The cartridges contain the media and therefore the flow-focusing is in response to the media and associated diameter of the cartridges.

Table 10. Vandenburg Results from the Design Tool for a 10-inch Well

Site Name: Vandenburg						
Input Parameter	Value	Units		Output Parameter	Value	Units
Target treatment width	150	ft		Treatment width	27	ft
Target treatment depth	20	ft		Number of wells	6	
k_{rxn}	0.0001	min^{-1}		Well length total	425	ft
Required retention time	5	days		Treatment length	64	ft
Actual retention time	12	days		Cost	272168	$
Treatment magnitude	3.2	OoM				
K_A	0.35	ft/d				
K_W	196	ft/d				
n	0.3					
b_A	7	ft				
i_A	0.007					
i_W	0.007					
Well diameter	10	in				
Cartridge diameter	8	in				
Active or passive	passive					
Active rate	NA	gpm				

Table 10 shows the results for a 10-inch diameter well. Here the treatment width has decreased to 27 ft as a result of decreased well diameter. In addition, as the aquifer thickness parameter increases the capture will decrease. For example, at a target depth of 8 ft a 12-inch well diameter (10-inch cartridge diameter) captures 38 ft, and a 10 inch well diameter (8-in cartridge diameter) capture 24 ft. The full output from the design tool for a 10-inch well at VAFB is included as **Attachment G-1**.

Three additional DoD sites were recently identified for pilot installations of the HRX Well. The first, named DoD-A, had an aquifer depth of 30 ft, aquifer conductivity of 0.74 ft/d and well media conductivity initially assumed as 57 ft/d. The combination of these factors suggested a small pump would be needed in situ to sufficiently increase flow rate and capture zone size. Therefore a 5 gpm (962 ft^3/day) was initially prescribed as shown in **Table 11**. It should be noted that this flow rate is an unreasonably high value for the site's aquifer transmissivity (K_A x b_A = 22 ft^2/day); however, this value was initially used to demonstrate the optimization processes.

Table 11. DoD-A Input Values for the Design Tool and Resulting Outputs

Site Name: DoD-A						
Input Parameter	Value	Units		Output Parameter	Value	Units
Target treatment width	45	ft		Treatment width	4336	ft
Target treatment depth	90	ft		Number of wells	1	
k_{rxn}	0.0009	min^{-1}		Well length total	2073	ft
Required retention time	3	days		Treatment length	459	ft
Actual retention time	8	days		Cost	1135404	$
Treatment magnitude	1.8	OoM				
K_A	0.74	ft/d				
K_W	57	ft/d				
n	0.25					
b_A	30	ft				
i_A	0.01					
i_W	0.01					
Well diameter	6	in				
Cartridge diameter	4	in				
Active or passive	Active					
Active rate	5	gpm				

At 5 gpm for the given site and according to Equation 1, the resulting effective well hydraulic conductivity (calculated by manipulation of the equation below) is 1.1E6 ft/d resulting in a calculated capture width of 4,336 ft, which is clearly unreasonably high.

$$Q = K_{media} * \pi * r^2 i_W$$

Equation 1. Flow rate due to media hydraulic conductivity and cartridge diameter.

Several iterations were then completed using the design tool to decrease the pump rate while monitoring capture width. The results of a pump rate of 0.05 gpm (9.6 ft^3/day), which is certainly sustainable for these aquifer conditions, are given in **Table 12**. The full output from the design tool for site DoD-A is included as **Attachment G-2**.

Table 12. Optimized Input and Output of DoD-A

Site Name: DoD-A					
Input Parameter	Value	Units	Output Parameter	Value	Units
Target treatment width	45	ft	Treatment width	43.2	ft
Target treatment depth	90	ft	Number of wells	1	
k_{rxn}	0.0009	min^{-1}	Well length total	981	ft
Required retention time	3	days	Treatment length	5	ft

Site Name: DoD-A					
Actual retention time	8	days	Cost	469493	$
Treatment magnitude	1.8	OoM			
K_A	0.74	ft/d			
K_W	57	ft/d			
n	0.25				
b_A	30	ft			
i_A	0.01				
i_W	0.01				
Well diameter	6	in			
Cartridge diameter	4	in			
Active or passive	Active				
Active rate	0.05	gpm			

The results in **Table 12** show that the capture width was reduced to 43.2 ft with a low and reasonable pumping rate; if the sustainable pumping rate can be increased. Alternatively, changes in input values would affect capture width, but may not be viable depending upon user requirements.

The second DoD site was called DoD-B and was contaminated with PFOS and PFOA. The site initially was presumed to not require an in situ pump and the associated results are shown in **Table 13**. The full output from the design tool for site DoD-B is included as **Attachment G-3**.

Table 13. Initial Input and Output values for DoD-B

Site Name: DoD-B					
Input Parameter	Value	Units	Output Parameter	Value	Units
Target treatment width	45	ft	Treatment width	0.56	ft
Target treatment depth	45	ft	Number of wells	90	
k_{rxn}	0.05	min^{-1}	Well length total	581	ft
Required retention time	0.1	days	Treatment length	42	ft
Actual retention time	0.2	days	Cost	317528	$
Treatment magnitude	3.1	OoM			
K_A	14.5	ft/d			
K_W	935	ft/d			
n	0.2				
b_A	10	ft			
i_A	0.037				
i_W	0.037				
Well diameter	6	in			
Cartridge diameter	4	in			
Active or passive	Passive				
Active rate	0	gpm			

Table 13 shows that, because of the relatively high aquifer hydraulic conductivity and thicker aquifer, the calculated capture width is very small, effectively the well diameter of 0.6 foot. If increases in well diameter were possible, then **Table 14** shows the result of doubling the well diameter.

Table 14. DoD-B Results When the Diameter was Increased to 12 Inches

Site Name: DoD-B					
Input Parameter	Value	Units	Output Parameter	Value	Units
Target treatment width	45	ft	Treatment width	4	ft
Target treatment depth	45	ft	Number of wells	14	
k_{rxn}	0.05	min^{-1}	Well length total	581	ft
Required retention time	0.1	days	Treatment length	42	ft
Actual retention time	0.2	days	Cost	308775	$
Treatment magnitude	3.1	OoM			
K_A	14.5	ft/d			
K_W	935	ft/d			

Site Name: DoD-B					
n	0.2				
b_A	10	ft			
i_A	0.037				
i_W	0.037				
Well diameter	12	in			
Cartridge diameter	10	in			
Active or passive	Passive				
Active rate	0	gpm			

The increased diameter increased capture width to 4 ft. Though the result is an improvement, it is not sufficient to achieve the target treatment width of 45 ft. Finally, the site was then changed to active and several pump rate values entered to achieve a reasonable capture width as shown in **Table 15**.

Table 15. DoD-B Updated Results from Adding a Small Pump

Site Name: DoD-B					
Input Parameter	Value	Units	Output Parameter	Value	Units
Target treatment width	45	ft	Treatment width	36	ft
Target treatment depth	45	ft	Number of wells	1	
k_{rxn}	0.05	min^{-1}	Well length total	486	ft
Required retention time	0.1	days	Treatment length	3	ft
Actual retention time	0.2	days	Cost	323550	$
Treatment magnitude	3.1	OoM			
K_A	14.5	ft/d			
K_W	935	ft/d			
n	0.2				
b_A	10	ft			
i_A	0.037				
i_W	0.037				
Well diameter	6	in			
Cartridge diameter	4	in			
Active or passive	Active*				
Active rate	1	gpm			

*Used pump rate to get reasonable capture and then the value to determine equivalent k_{W}.

The resulting capture width was 36 ft when the pump rate was exactly 1.0 gpm (192 ft^3/day), which is likely a reasonable sustainable yield for the transmissivity of this aquifer (K_A x b_A = 145 ft^2/day). As with DoD-A, the rate could be further optimized to increase capture, or other parameters altered if possible.

A third DoD site was identified where the primary contaminants of concern were 1,4 dioxane and trichloroethene (TCE). The site information is detailed in **Table 16**. The full output from the design tool for site DoD-B is included as **Attachment G-4**.

Table 16. DoD-C Updated Results from Adding a Small Pump

Site Name: DoD-B					
Input Parameter	Value	Units	Output Parameter	Value	Units
Target treatment width	185	ft	Treatment width	79	ft
Target treatment depth	10	ft	Number of wells	1*	
k_{rxn}	0.003	min^{-1}	Well length total	423	ft
Required retention time	0.9	days	Treatment length	106	ft
Actual retention time	2.4	days	Cost	293,232	$
Treatment magnitude	1.8	OoM			
K_A	0.142	ft/d			
K_W	283	ft/d			
n	0.35				
b_A	5	ft			
i_A	0.055				
i_W	0.055				
Well diameter	8	in			
Cartridge diameter	6	in			
Active or passive	Passive				
Active rate	NA	gpm			

*In order to address the target plume width of 185 ft, three wells would be required. The site is intended as a pilot installation and therefore only one well will be installed.

The capture width for DoD-C was determined to be 79 ft based on initial input values. There was enough hydraulic conductivity contrast such that neither a pump nor mix-in media was required to achieve reasonable capture.

4 SUSTAINABILITY ASSESSMENT OF THE HRX WELL

The tool was used to complete a sustainability analysis for the demonstration project at VAFB. To maximize benefits of a remediation system the associated environmental impacts from materials, installation, and use should be minimized. The SiteWise program (Battelle, U.S. Army Corps of Engineers) was used to assess three remediation systems designed to accomplish similar treatment goals. The goal of the assessment was to provide sufficient data to compare the HRX Well to other commonly used remediation systems, in terms of lifecycle impacts. The system boundary was around direct inputs including materials, energy sources, and equipment use. Equipment manufacture and transport was not included, however, personnel transport during installation, and materials transport to the site was included. Direct system installation was included but not construction of buildings, roads, or other infrastructure. Each remediation alternative (**Table 17**) was divided into three phases. Phase 1- materials manufacture, Phase 2- system installation, and Phase 3- system operation. Operation was considered either active or passive. where passive impacts were media replacements. The data for each phase of each alternative was entered into the SiteWise input sheet one at a time so impacts could be clearly assessed separately. The results of each analysis are given in **Figures 2** through **4** which depict greenhouse gas (GHG) emissions, energy use, and NOx, SOx, and PM_{10} emissions.

Table 17 includes the values and assumptions for each alternative. Alternative 1 was the HRX Well, Alternative 2 a groundwater extraction and treatment system (GETS), and Alternative 3 a permeable reactive barrier all intended to target a TCE plume. It is important to note that each alternative does necessarily appear equivalent in terms of total materials mass or method of operation.

Table 17A – D. Inputs used in SiteWise for Three Remediation Alternatives Considered in Three Phases

Table 14A				
System/Phase	**Assumption**	**Input**	**Value**	**Units**
Site	Contaminant: Trichloroethylene	Plume dimensions	(l) 500 (w) 150 (d) 25	ft
Travel	7 personnel	Air travel total	24328	miles
	7 personnel	Car travel total- 25 mpg car	207	miles
Travel/HRX	Equipment- shared long-road	Total materials weight	24	tons
Travel/GETS	Equipment- shared long-road	Total materials weight	28	tons
Travel/PRB	Equipment- shared long-road	Total materials weight	1267	tons
	Max 40 tons of materials per truck	31 trips	40	tons/trip

Table 17B				
System/Phase	**Assumption**	**Input**	**Value**	**Units**
HRX/Phase 1	3 wells	Diameter	1	ft
	Well casing:	Sc 40 PVC Casing	265	ft
	Well screen	Sc 40 St. steel screen	165	ft
	13 5ft cartridges, Sch 40 SS	Diameter	1	ft
	75% reactive media	ZVI (per well)	630	kg
	5% casing grout	Bentonite (per well)	94	kg
	95% casing grout	Typical cement (per well)	179	kg
HRX/Phase 2	Drilling operations from Lubrecht 2012	0.086 hrs/ft	37	hours
	Excavator	Soil removed per well	6.6	yd^3
	Water-development	12 gallons/ft well; total for 3 wells	721	gallons
HRX/Phase 3	1 media replacement at 15 years	630 kg per well	1890	kg

Table 17C				
System/Phase	**Assumption**	**Input**	**Value**	**Units**
GETS/Phase 1	10 vertical wells	Diameter	0.5	ft
	Well casing:	Sc 40 PVC (total ft)	120	ft
	Well screen	Sc 40 st steel (total ft)	100	ft
	Grout 5%	Bentonite (total mass)	500	kg
	Grout 95%	Typical cement (total mass)	5210	kg
	Virgin GAC, 2 replacements/year	Total mass per replacement	3325	lbs

Table 17C				
System/Phase	**Assumption**	**Input**	**Value**	**Units**
GETS/Phase 2	Drill rig	0.086 hrs/ft (total for 10 wells)	10.32	hours
	Excavator	Cubic yards soil removed	122	yd^3
	Water-development	Gallons used per well (and assumed 50% recovered to WWTP)	721	gallons
GETS/Phase 3	10 extraction pumps	2 hp each (05 gpm each) (total hp given). Assume 24 hrs operation/day.	20	hp
	1 compressor	2 hp compressor. Assume 24 hrs operation/day.	2	hp
	1 system pump	4 hp pump. Assume 24 hrs operation/day.	4	hp
	GAC Replacement (annual)	Total mass	3325	lbs

Table 17D				
System/Phase	**Assumption**	**Input**	**Value**	**Units**
PRB/Phase 1	25% treatment media	ZVI (total)	214096	kg
	Sand (35%)	Total mass	398254	kg
	Portland cement (3%)	Total mass	18143	kg
PRB/Phase 2	Trencher 16-25 hp and 300 linear ft/day (CHM Report)	Operating time (25*150)	75	hours
	Excavator removed soil	Cubic yards removed	450	yd^3
PRB/Phase 3	1 media replacement at 15 years	Total ZVI	214096	kg

Table 17D				
System/Phase	**Assumption**	**Input**	**Value**	**Units**
	1 sand (35%) replacement at 15 years	Total mass	398254	kg
	1 Portland cement (3%) replacement at 15 years	Total mass	18143	kg

4.1 Emissions Impacts

Table 14 demonstrates that impacts of each system will vary. For example, the mass of materials transported and used in each system was much greater for the PRB than GETS or the HRX Well. The resulting GHG emissions from all phases are shown in **Figure 2**. Clearly, operation of the GETS system (GETS-3), shown as annual operation, had the greatest impact overall due to continuous operation of extraction and system pumps, in addition to a blower. Further comparison shows that in the travel phase PRB-related transport was greater than the HRX Well or GETS because of the much larger mass of ZVI used. However, in comparison to GETS operation, the PRB media is only replaced once during the system lifetime making PRB-3 much lower than GETS-3. PRB media manufacture similarly was greater than the other alternatives. GHG emissions were higher for HRX-1 than GETS-1 though the impacts are clearly offset by the GHG emissions avoided by use of passive water capture and treatment. HRX-3 has a slight impact as a result of media replacements while PRB-3 is higher due to the replacement halfway through its lifecycle.

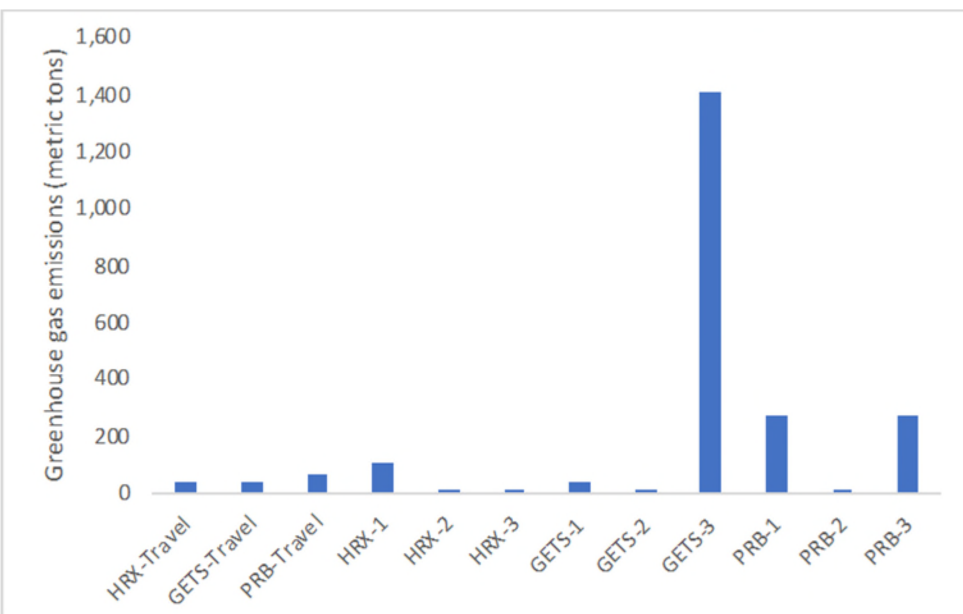


Figure 2. Greenhouse Gas Emissions Resulting from Three Lifecycle Phases (Manufacture, Installation, Operation) for Three Remediation Alternatives

Materials manufacturing resulted in more emissions to air in the order of PRB>HRX Well>GETS. The same order was observed for Phase 2 except that only NOx is visible in **Figure 3** as it is the primary impact of installation and related to the equipment type used. In Phase 3, again, the HRX Well had substantially lower impacts than the other two alternatives, and the impacts were lower than HRX Well in Phase 1. In Phase 1 the well materials were also manufactured increasing emissions. Due to specific methods of operation the NOx, SOx, and PM_{10} emissions vary from GETS to the PRB. For example, because GETS requires electricity for operation, and in turn fossil fuel combustion to produce the electricity, NOx emissions were greater. However, more SOx and PM_{10} were produced during PRB media replacement as a result of ZVI processing.

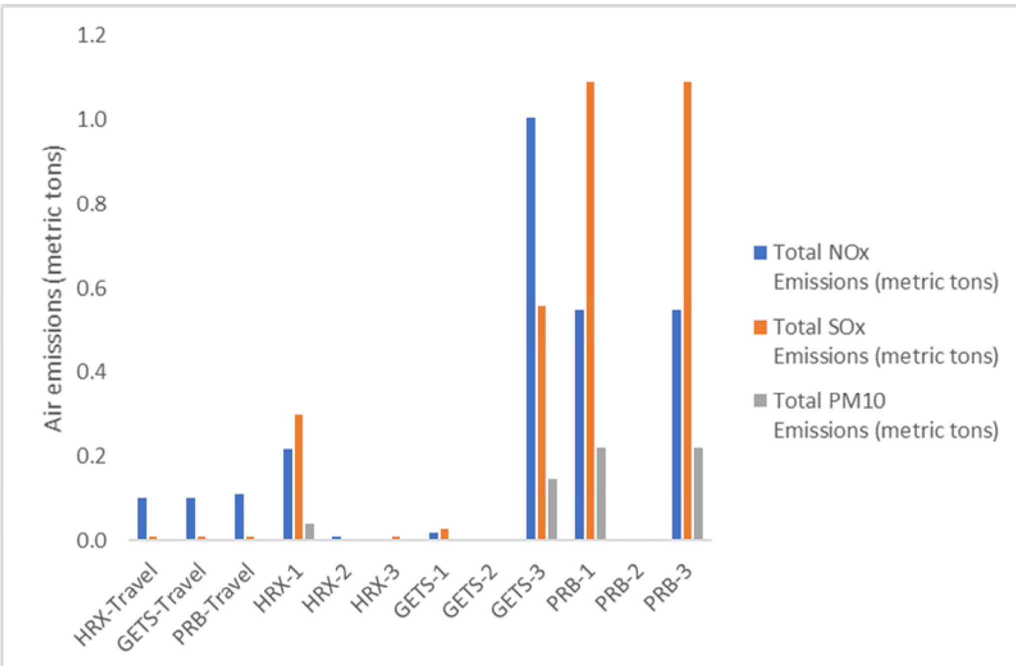


Figure 3. NOx, SOx, and PM_{10} Emissions Resulting from the Lifecycles of Three Remediation Alternatives Considered for Remediation of a TCE Plume

The HRX Well did not have uniformly lower impacts. Comparison of total lifecycle impacts, as a sum of impacts in each phase, showed that the HRX Well has the lowest impact overall. The difference is particularly evident in Phase 3 where impacts in Phase 1 and Phase 2 are not carried through operations. By passively treating contaminants the same remediation goal can be achieved with reduced impacts. As a result, the remediation outcome is improved when emissions impacts are avoided.

4.2 Energy Impacts

Energy use (in millions of BTUs) was also characterized and is shown in **Figure 4.** Travel impacts were relatively similar as for GHG gas emissions. The order of energy use for materials manufacture was in the same order as travel, which was also implied in **Table 14** by the materials used. Despite the use of heavy equipment to install all three alternatives the Phase 2 energy use was uniformly low compared to all other phases. In Phase 3 the HRX Well clearly outperformed both GETS and the PRB due to passive operation and comparatively less reactive media used, respectively. GETS operation was assumed to be continuous and the PRB media mass used (214096 kg ZVI) was much greater than that in the three HRX Wells (1890 kg). While the PRB passively intercepts contaminant plumes the mass of reactive media required has a much more significant impact.

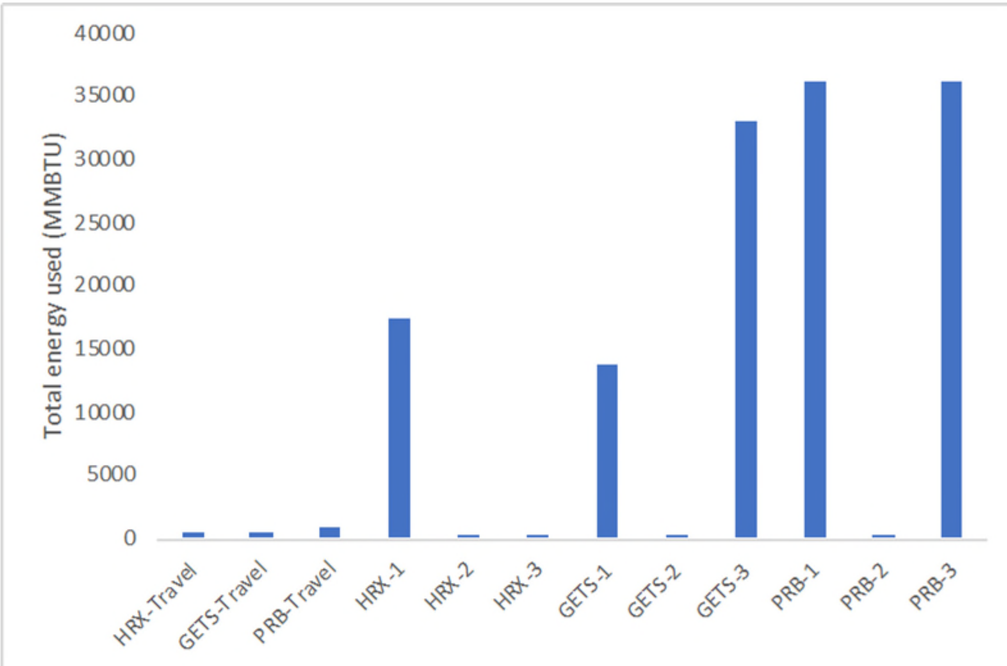


Figure 4. Total Energy Used in Millions of BTUs for Three Remediation Alternatives by Lifecycle Phase

4.3 Resource Impacts

Based on the inputs from each table and the resulting emissions data, the natural resource impacts from the HRX Well are minimized in comparison to GETS or PRB. The HRX Well is capable of meeting remediation goals while minimizing natural resource consumption. For example, the efficient use of ZVI by the HRX Well where the mass of ZVI used in the system lifecycle is a fraction of that used by the PRB. The HRX Well is also passive and therefore does not require extraction of fossil fuels, water, or other recurring materials (other than a single media replacement after 15 years) to meet remediation goals.

4.4 On-Site Safety

The lifecycle phases of the HRX Well were not found to present unusual risks to workers. In some cases, risks were minimized compared to the alternatives. The HRX Well is an in situ system and thus does not require contaminants to be removed from the aquifer thereby reducing worker exposure. Installation activities were closely monitored, and worker safety was prioritized. The HRX Well operates in situ and passively which also does not introduce risk from operation and maintenance activities. In comparison to the alternatives the HRX Well does not pose exceptional risks or risks out of proportion with the sustainability benefits.

5 REFERENCES

Divine, C.E., Wright, J., Wang, J., McDonough, J., Kladias, M., Crimi, M., Nzeribe, B.N., Devlin, J.F., Lubrecht, M., Ombalski, D., Hodge, W., Voscott, H., Gerber, K. 2018. The Horizontal Reactive Media Treatment Well (HRX Well®) for Passive In Situ Remediation: Design, Implementation, and Sustainability. Remediation Journal 28 (4), 5-16.

Attachment G-1

VAFB

Cell Key	Enter value	Select value	Calculated value	Required value to get capture width

Contaminant information

Enter:

1. Plume dimensions- Note that these are target treatment dimensions which may not be equal to the total plume. Plume length is not used in calculations. Instead, treatment length is calculated below using user-provided rate constants or those from the lookup tables.
2. Contaminant concentration- see below
3. Media porosity-This value should typically fall between 0.2 and 0.5
4. Treatment goals as percent reduction or a final concentration, including specific regulatory limits.

If treatability testing was not completed enter estimated values.

If more than one contaminant is present and part of the HRX Well(R) treatment plan do the following:

1. Enter one contaminant initial concentration and treatment goal. This can be in random order or address a primary contaminant of concern first. Note that known rate constants are entered in P32 or selected with media options in P35.
2. Take note of the resulting treatment and well lengths.
3. If two or more contaminants are present and part of the treatment plan repeat steps 1 and 2.
4. From the resulting well lengths use the longest treatment length to ensure the longest retention time required is achieved.

NOTE 1: Treatment lengths for two more more contaminants that are chemically dissimilar and or present in different concentrations should not be assumed correct without laboratoy verification from batch or column tests of the site groundwater containing the contaminants of concern.

NOTE 2: Use psuedo first-order rate constant for adsorptive media.

Tool input description	Value
General Site Info	
Site Name	VAFB
Site Location	CA
Known contaminant:	TCE

Contaminant information	
Target treatment width (ft)	150
Target treatment depth (ft)	20
Initial contaminant concentration (ug/L)	75000

Treatment goals	Value
Percent reduction (%)	
or	
Concentration (ug/L)	50

Unit Conversions

Enter hydraulic conductivity in ft/d to get value in cm/s	
Hydraulic conductivity in cm/s	0
If concentration is in molar units enter value	
Enter contaminant molecular weight	
Concentration in ug/L	0

Other helpful conversion factors

	86400 seconds
1 foot	30.48 cm
1 gpm	192.5 ft^3/d
1 gallon	3.785 L
PPT	ng/L
PPB	ug/L
PPM	mg/L

Site information

Enter values from site investigations and treatability testing. If information is not available use best estimates.

The HRX Well® hydraulic gradient should be assumed approximately equal to the aquifer hydraulic gradient. Item **F** on the adjacent diamgram show

Aquifer Properties		Value (secondary units)
Enter site hydraulic conductivity *K* (cm/s; ft/d)	1.23E-04	0.350
Enter site hydraulic gradient i	0.007	
Enter aquifer thickness b_a (ft)	7	
Enter site transmissivity *T* (cm^2/s; ft^2/d)	0.026	2.450

Treatment media information

Enter data from treatability testing in M32, N32, and O32 will auto-fill.
If treatability testing was not completed select reference values from M35 and N35 (O35 will autofill).
Enter media density from known values or from Q2:Q13 in the Lookup Tables tab
Enter a media capacity value in M39. If the value is not known enter the partitioning coefficient and the capacity will be estimated using the concentration data provided above.
Enter media partition coefficient (measured or from literature) and the changeout freqeuncy will be calculated assuming changeout occurs at 70% of media capacity.

Enter or select contaminant and media values

Contaminant	Media	Media hydraulic conducitvity (cm/s)	Media hydraulic conducitvity (ft/day)	Enter $k_{contaminant}$ (min^{-1})	Calculated half-life (days)
TCE	ZVI	0.069	196	9.00E-04	0.5

Contaminant	Select	Media hydraulic conductivity (cm/s)	Media hydraulic conducitvity (ft/day)	$k_{contaminant}$ (min^{-1})
Select	Select	#N/A	#N/A	#N/A

Enter treatment media porosity *n*	0.3
Enter media density value (kg/m^3)	2100
Media capacity (mg/kg)	
Media K_d (L/kg)	
Enter cost per kg of treatment media	$1.64

Active and passive sites

Active sites are those with hydraulic conductivity greater than 5 ft/d
Passive sites have hydrulic conductivity less than 5 ft/d
If site is active enter the gpm value from pumping tests.
Cell H8 under the Summary tab will display if the site is active or passive.
If sufficient capture is not achieved with the reactive media alone, a pump rate can be entered to increase capture width.
NOTE; That increasing flow rate into the well will cause well length to increase if reaction rates remain the same.

Select "Active" if the site will use a pump	Passive
If active, enter gpm value	

Explanation of mix-in media

Mix-in media was included in the design tool in order to optimize hydraulic conductivity (and related parameters) in the cartridges. These media are not reactive but it should be noted that using too much will reduce the total available surface area of treatment media. The mix-in media are useful when hydraulic conductivity is too high or too low for the treatment media. In these scenarios the retention time determined from reaction rate constants may not be achieved. Changing the hydraulic conductivity in the cartridge is one method of specifying the cartridge retention time.
Note that the weighted media hydraulic conductivity is an *estimate* only. For a thorough analysis refer to HydrogeoSieveXL2 (http://people.ku.edu/~jfdevlin/Software.html)

Select mix-in media	Mix-in media K (cm/s)
Gravel	3.00E+00

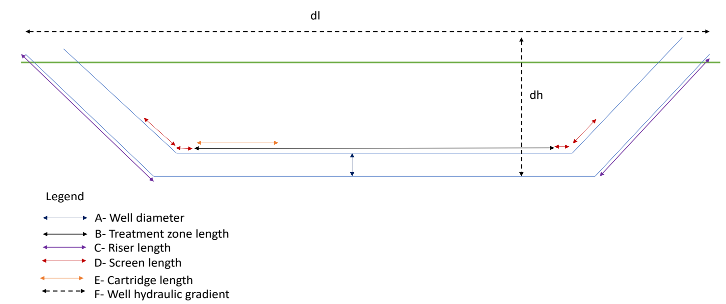
Enter % of mix in media	Percent reaction media (%)
0.00%	100.00%

Weighted K_{media} (ft/d)	196

Well parameters

Select HRX Well® diameter.
The remaining values are automatically calculated in a separate tab and returned here.
A reference diagram is provided to the right- match letters next to input cells to diagram.
The cartridge diameter is assumed to be 2 inches less than the HRX Well® diameter.
Enter well hydraulic gradient. The value should be approximately equal to the aquifer hydraulic gradient.

Well parameters	
A Select HRX Well® diameter (in)	10
B Minimum treatment zone length (ft)	64
C Riser length (ft)	200
D Total screen length (ft)	160
Total HRX Well® length (ft)	425
E Number of 10 ft cartridges	8
Drill time (Hrs)	37
Select well casing material	Carbon steel
F HRX Well® hydraulic gradient	0.007



General Site Info	Value
Site Name	VAFB
Site Location	CA
Known contaminant type 1:	TCE
Known contaminant concentration (ug/L)	75000
Treatment goals	
Percent reduction (%)	0.000
or	
Concentration (ug/L)	50
Tool setup	
Select contaminant category	TCE
Compatible media	ZVI
Media hydraulic conductivity (ft/d)	196
Media reactivity (min^{-1})	9.00E-04

Data Summary

The first block (Outputs from User Inputs gab) summarzies the well design based on the inputs in that tab. If the results shown are not practical input values can be adjusted where reasonable (i.e. aquifer hydraulic conductivity cannot practically be altered).

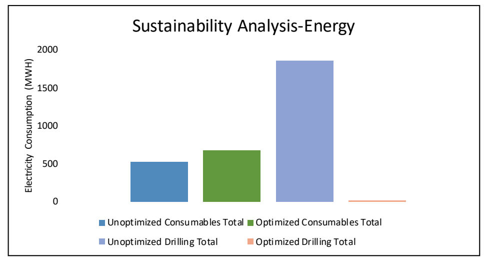
The second block will display updated values if mix-in media or a pump is added.

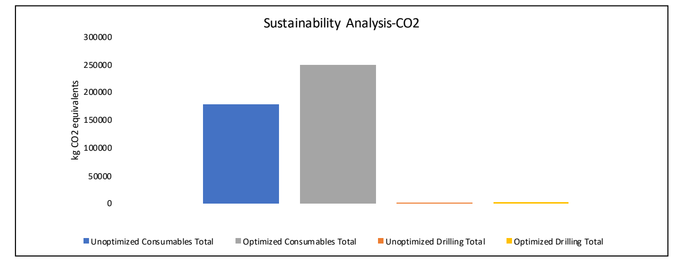
Outputs from User Input tab	Result
Well average capture width (ft)	28
Number of wells	6
Well HRT (days)	14.1
Contaminant HRT required (days)	5.6
Well length (ft)	425
Site is active or passive	Passive
Active pumping rate (gpm)	0.000
Cartridge length (ft)	10
Number of cartridges	5
Total capital cost **per well** (USD)	$272,168
Initial cost of reaction media (USD)	$4,784
Media changeout frequency (years)	0
Annual media changeout cost (USD)	30,000
Consumables total (kg CO_2 e)	177853
Consumables total (g NOx)	282663
Consumables total (g SOx)	392332
Consumables total (g PM10)	50743
Consumables total (MJ)	1863822
Consumables total (MWH)	518
Annual media changeouts (kg CO_2 e)	0
Drilling total (kg CO_2 e)	1914
Drilling total (g NOx)	22
Drilling total (g SOx)	2157
Drilling total (g PM10)	19861
Drilling total (MJ)	2480
Drilling total (MWH)	1852
Drilling for changeouts kg CO_2 e)	0

Results from mix-in media or added pump	Result
Well average capture width (ft)	28
Number of wells	6
Well HRT (days)	6
Well length (ft)	292
Active pumping (gpm)	0.000
Cartridge length (ft)	10
Number of 10 ft cartridges	3
Total capital cost (USD)	$183,397
Total cost of reaction media (USD)	$0
Consumables total (kg CO_2 e)	250528
Consumables total (g NOx)	428634
Consumables total (g SOx)	582123
Consumables total (g PM10)	73933
Consumables total (MJ)	2423356
Consumables total (MWH)	673
Drilling total (kg CO_2 e)	22
Drilling total (g NOx)	0
Drilling total (g SOx)	24
Drilling total (g PM10)	224
Drilling total (MJ)	28
Drilling total (MWH)	21

Cartridge length (ft)	Number for initial well length
5	13
10	6

Cartridge length (ft)	Number for well length
5	5
10	3





Interpreting Sustainability Results

Example sustainability data and external comparisons are given in the table below to give context to sustainability data outputs.

The site had target plume width of 150 ft and target depth of 20 ft. The well was *450* ft long and the

Impact category for consumables	Associated CO_2 eq emissions (kg)	Associated NO_x Emissions (g)
Consumables emissions	496151	786333
Equivalent to driving n passenger cars per year	105	49730
Drilling emissions	5303	60
Equivalent to driving n passenger cars per year	1.1	3.8

Attachment G-2

Site A

Cell Key	Enter value	Select value	Calculated value	Required value to get capture width

Contaminant information

Enter:

1. Plume dimensions- Note that these are target treatment dimensions which may not be equal to the total plume. Plume length is not used in calculations. Instead, treatment length is calculated below using user-provided rate constants or those from the lookup tables.
2. Contaminant concentration- see below
3. Media porosity-This value should typically fall between 0.2 and 0.5
4. Treatment goals as percent reduction or a final concentration, including specific regulatory limits.

If treatability testing was not completed enter estimated values.

If more than one contaminant is present and part of the HRX Well(R) treatment plan do the following:

1. Enter one contaminant initial concentration and treatment goal. This can be in random order or address a primary contaminant of concern first. Note that known rate constants are entered in P32 or selected with media options in P35.
2. Take note of the resulting treatment and well lengths.
3. If two or more contaminants are present and part of the treatment plan repeat steps 1 and 2.
4. From the resulting well lengths use the longest treatment length to ensure the longest retention time required is achieved.

NOTE 1: Treatment lengths for two more more contaminants that are chemically dissimilar and or present in different concentrations should not be assumed correct without laboratoy verification from batch or column tests of the site groundwater containing the contaminants of concern.

NOTE 2: Use psuedo first-order rate constant for adsorptive media.

Tool input description	Value
General Site Info	
Site Name	DoD-A
Site Location	
Known contaminant:	TCE, PCE
Contaminant information	
Target treatment width (ft)	45
Target treatment depth (ft)	90
Initial contaminant concentration (ug/L)	320

Treatment goals	Value
Percent reduction (%)	
or	
Concentration (ug/L)	5

Unit Conversions

Enter hydraulic conductivity in ft/d to get value in cm/s
Hydraulic conductivity in cm/s
If concentration is in molar units enter value
Enter contaminant molecular weight
Concentration in ug/L

Other helpful conversion factors

1 foot
1 gpm
1 gallon
PPT
PPB
PPM

Site information

Enter values from site investigations and treatability testing. If information is not available use best estimates.

The HRX Well® hydraulic gradient should be assumed approximately equal to the aquifer hydraulic gradient. Item **F** on the adjacent diamgram show

Aquifer Properties		Value (secondary units)
Enter site hydraulic conductivity K (cm/s; ft/d)	2.61E-04	0.740
Enter site hydraulic gradient i	0.01	
Enter aquifer thickness b_a (ft)	30	
Enter site transmissivity T (cm^2/s; ft^2/d)	0.239	22.195

Treatment media information

Enter data from treatability testing in M32, N32, and O32 will auto-fill.
If treatability testing was not completed select reference values from M35 and N35 (O35 will autofill).
Enter media density from known values or from Q2:Q13 in the Lookup Tables tab
Enter a media capacity value in M39. If the value is not known enter the partitioning coefficient and the capacity will be estimated using the concentration data provided above.
Enter media partition coefficient (measured or from literature) and the changeout freqeuncy will be calculated assuming changeout occurs at 70% of media capacity.

Enter or select contaminant and media values

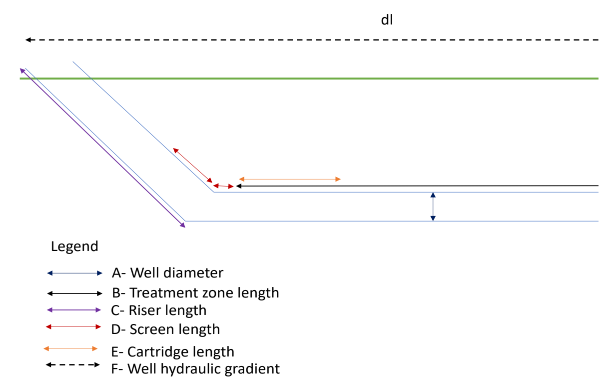
Contaminant	Media	Media hydraulic conducitvity (cm/s)	Media hydraulic conducitvity (ft/day)
TCE, PCE	ZVI	0.02	57
Contaminant	**Select**	**Media hydraulic conductivity (cm/s)**	Media hydraulic conducitvity (ft/day)
Select	Select	#N/A	#N/A

Enter treatment media porosity n	0.25
Enter media density value (kg/m^3)	2100
Media capacity (mg/kg)	
Media K_d (L/kg)	
Enter cost per kg of treatment media	$1.64

Active and passive sites

Active sites are those with hydraulic conductivity greater than 5 ft/d
Passive sites have hydrulic conductivity less than 5 ft/d
If site is active enter the gpm value from pumping tests.
Cell H8 under the Summary tab will display if the site is active or passive.
If sufficient capture is not achieved with the reactive media alone, a pump rate can be entered to increase capture width.
NOTE; That increasing flow rate into the well will cause well length to increase if reaction rates remain the same.

Select "Active" if the site will use a pump	Active
If active, enter gpm value	0.050



Explanation of mix-in media

Mix-in media was included in the design tool in order to optimize hydraulic conductivity (and related parameters) in the cartridges. These media are not reactive but it should be noted that using too much will reduce the total available surface area of treatment media. The mix-in media are useful when hydraulic conductivity is too high or too low for the treatment media. In these scenarios the retention time determined from reaction rate constants may not be achieved. Changing the hydraulic conductivity in the cartridge is one method of specifying the cartridge retention time.
Note that the weighted media hydraulic conductivity is an *estimate* only. For a thorough analysis refer to HydrogeoSieveXL2 (http://people.ku.edu/~jfdevlin/Software.html)

Select mix-in media	Mix-in media K (cm/s)
Gravel	3.00E+00

Enter % of mix in media	Percent reaction media (%)
0.00%	100.00%

Weighted K_{media} (ft/d)	11029

Well parameters

Select HRX Well® diameter.
The remaining values are automatically calculated in a separate tab and returned here.
A reference diagram is provided to the right- match letters next to input cells to diagram.
The cartridge diameter is assumed to be 2 inches less than the HRX Well® diameter.
Enter well hydraulic gradient. The value should be approximately equal to the aquifer hydraulic gradient.

Well parameters	
A Select HRX Well® diameter (in)	6
B Minimum treatment zone length (ft)	1
C Riser length (ft)	900
D Total screen length (ft)	72
Total HRX Well® length (ft)	973
E Number of 10 ft cartridges	0
Drill time (Hrs)	84
Select well casing material	Carbon steel
F HRX Well® hydraulic gradient	0.01

General Site Info	Value
Site Name	DoD-A
Site Location	0
Known contaminant type 1:	TCE, PCE
Known contaminant concentration (ug/L)	320
Treatment goals	
Percent reduction (%)	0.000
or	
Concentration (ug/L)	5
Tool setup	
Select contaminant category	TCE, PCE
Compatible media	ZVI
Media hydraulic conductivity (ft/d)	57
Media reactivity (min^{-1})	3.00E-03

Data Summary

The first block (Outputs from User Inputs gab) summarzies the well design based on the inputs in that tab. If the results shown are not practical input values can be adjusted where reasonable (i.e. aquifer hydraulic conductivity cannot practically be altered).

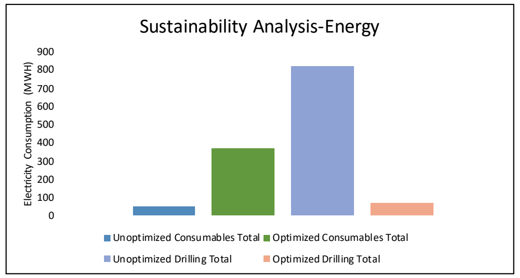
The second block will display updated values if mix-in media or a pump is added.

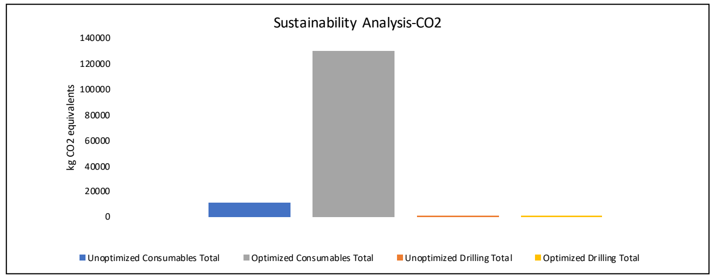
Outputs from User Input tab	Result
Well average capture width (ft)	43
Number of wells	1
Well HRT (days)	2.4
Contaminant HRT required (days)	1.0
Well length (ft)	973
Site is active or passive	Passive
Active pumping rate (gpm)	0.050
Cartridge length (ft)	10
Number of cartridges	19
Total capital cost **per well** (USD)	$469,493
Initial cost of reaction media (USD)	$26
Media changeout frequency (years)	0
Annual media changeout cost (USD)	30,000
Consumables total (kg CO_2 e)	10857
Consumables total (g NOx)	21230
Consumables total (g SOx)	31511
Consumables total (g PM10)	4292
Consumables total (MJ)	173178
Consumables total (MWH)	48
Annual media changeouts (kg CO_2 e)	0
Drilling total (kg CO_2 e)	846
Drilling total (g NOx)	10
Drilling total (g SOx)	954
Drilling total (g PM10)	8779
Drilling total (MJ)	1096
Drilling total (MWH)	818
Drilling for changeouts kg CO_2 e)	0

Results from mix-in media or added pump	Result
Well average capture width (ft)	43
Number of wells	1
Well HRT (days)	1
Well length (ft)	1949
Active pumping (gpm)	0.050
Cartridge length (ft)	10
Number of 10 ft cartridges	42
Total capital cost (USD)	$1,053,095
Total cost of reaction media (USD)	$0
Consumables total (kg CO_2 e)	129772
Consumables total (g NOx)	258648
Consumables total (g SOx)	351283
Consumables total (g PM10)	44618
Consumables total (MJ)	1342935
Consumables total (MWH)	373
Drilling total (kg CO_2 e)	69
Drilling total (g NOx)	1
Drilling total (g SOx)	77
Drilling total (g PM10)	713
Drilling total (MJ)	89
Drilling total (MWH)	66

Cartridge length (ft)	Number for initial well length
5	0
10	0

Cartridge length (ft)	Number for well length
5	85
10	42





Interpreting Sustainability Results

Example sustainability data and external comparisons are given in the table below to give context to sustainability data outputs.

The site had target plume width of 150 ft and target depth of 20 ft. The well was *450* ft long and the

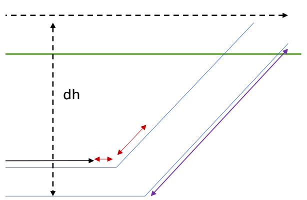
Impact category for consumables	Associated CO_2 eq emissions (kg)	Associated NO_x Emissions (g)
Consumables emissions	496151	786333
Equivalent to driving n passenger cars per year	105	49730
Drilling emissions	5303	60
Equivalent to driving n passenger cars per year	1.1	3.8

0
0

86400 seconds
30.48 cm
192.5 ft^3/d
3.785 L
ng/L
ug/L
mg/L

Enter $k_{contaminant}$ (min^{-1})	Calculated half-life (days)
3.00E-03	0.2

$k_{contaminant}$ (min^{-1})
#N/A



Attachment G-3

Site B

Cell Key	Enter value	Select value	Calculated value	Required value to get capture width

Contaminant information
Enter:
1. Plume dimensions- Note that these are target treatment dimensions which may not be equal to the total plume. Plume length is not used in calculations. Instead, treatment length is calculated below using user-provided rate constants or those from the lookup tables.
2. Contaminant concentration- see below
3. Media porosity-This value should typically fall between 0.2 and 0.5
4. Treatment goals as percent reduction or a final concentration, including specific regulatory limits.

If treatability testing was not completed enter estimated values.

If more than one contaminant is present and part of the HRX Well(R) treatment plan do the following:
1. Enter one contaminant initial concentration and treatment goal. This can be in random order or address a primary contaminant of concern first. Note that known rate constants are entered in P32 or selected with media options in P35.
2. Take note of the resulting treatment and well lengths.
3. If two or more contaminants are present and part of the treatment plan repeat steps 1 and 2.
4. From the resulting well lengths use the longest treatment length to ensure the longest retention time required is achieved.

NOTE 1: Treatment lengths for two more more contaminants that are chemically dissimilar and or present in different concentrations should not be assumed correct without laboratoy verification from batch or column tests of the site groundwater containing the contaminants of concern.
NOTE 2: Use psuedo first-order rate constant for adsorptive media.

Tool input description	Value
General Site Info	
Site Name	DoD-B
Site Location	
Known contaminant:	PFOA, PFOS
Contaminant information	
Target treatment width (ft)	45
Target treatment depth (ft)	45
Initial contaminant concentration (ug/L)	80

Treatment goals	Value
Percent reduction (%)	
or	
Concentration (ug/L)	0.07

Unit Conversions

Enter hydraulic conductivity in ft/d to get value in cm/s	
Hydraulic conductivity in cm/s	0
If concentration is in molar units enter value	
Enter contaminant molecular weight	
Concentration in ug/L	0

Other helpful conversion factors

	86400 seconds
1 foot	30.48 cm
1 gpm	192.5 ft^3/d
1 gallon	3.785 L
PPT	ng/L
PPB	ug/L
PPM	mg/L

Site information
Enter values from site investigations and treatability testing. If information is not available use best estimates.

Aquifer Properties		Value (secondary units)
Enter site hydraulic conductivity *K* (cm/s; ft/d)	5.11E-03	14.485
Enter site hydraulic gradient i	0.037	
Enter aquifer thickness b_a (ft)	10	
Enter site transmissivity *T* (cm^2/s; ft^2/d)	1.558	144.850

Treatment media information
Enter data from treatability testing in M32, N32, and O32 will auto-fill.
If treatability testing was not completed select reference values from M35 and N35 (O35 will autofill).
Enter media density from known values or from Q2:Q13 in the Lookup Tables tab
Enter a media capacity value in M39. If the value is not known enter the partitioning coefficient and the capacity will be estimated using the concentration data provided above.
Enter media partition coefficient (measured or from literature) and the changeout freqeuncy will be calculated assuming changeout occurs at 70% of media capacity.

Enter or select contaminant and media values

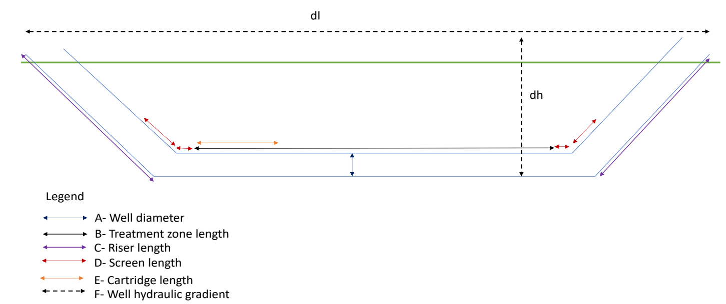
Contaminant	Media	Media hydraulic conducitvity (cm/s)	Media hydraulic conducitvity (ft/day)	Enter $k_{contaminant}$ (min^{-1})	Calculated half-life (days)
PFOA, PFOS	GAC, ZVI	0.33	935	3.00E-03	0.2

Contaminant	Select	Media hydraulic conductivity (cm/s)	Media hydraulic conducitvity (ft/day)	$k_{contaminant}$ (min^{-1})
Select	Select	#N/A	#N/A	#N/A

Enter treatment media porosity *n*	0.2
Enter media density value (kg/m^3)	2100
Media capacity (mg/kg)	
Media K_d (L/kg)	
Enter cost per kg of treatment media	$1.64

Active and passive sites
Active sites are those with hydraulic conductivity greater than 5 ft/d
Passive sites have hydrulic conductivity less than 5 ft/d
If site is active enter the gpm value from pumping tests.
Cell H8 under the Summary tab will display if the site is active or passive.
If sufficient capture is not achieved with the reactive media alone, a pump rate can be entered to increase capture width.
NOTE; That increasing flow rate into the well will cause well length to increase if reaction rates remain the same.

Select "Active" if the site will use a pump	Active
If active, enter gpm value	1.000



Explanation of mix-in media
Mix-in media was included in the design tool in order to optimize hydraulic conductivity (and related parameters) in the cartridges. These media are not reactive but it should be noted that using too much will reduce the total available surface area of treatment media. The mix-in media are useful when hydraulic conductivity is too high or too low for the treatment media. In these scenarios the retention time determined from reaction rate constants may not be achieved. Changing the hydraulic conductivity in the cartridge is one method of specifying the cartridge retention time.
Note that the weighted media hydraulic conductivity is an *estimate* only. For a thorough analysis refer to HydrogeoSieveXL2 (http://people.ku.edu/~jfdevlin/Software.html)

Select mix-in media	Mix-in media K (cm/s)
Gravel	3.00E+00

Enter % of mix in media	Percent reaction media (%)
0.00%	100.00%

Weighted K_{media} (ft/d)	59619

Well parameters
Select HRX Well® diameter.
The remaining values are automatically calculated in a separate tab and returned here.
A reference diagram is provided to the right- match letters next to input cells to diagram.
The cartridge diameter is assumed to be 2 inches less than the HRX Well® diameter.
Enter well hydraulic gradient. This value should be approximately equal to the aquifer hydraulic gradient.

Well parameters	
A Select HRX Well® diameter (in)	6
B Minimum treatment zone length (ft)	47
C Riser length (ft)	450
D Total screen length (ft)	95
Total HRX Well® length (ft)	592
E Number of 10 ft cartridges	6
Drill time (Hrs)	51
Select well casing material	Carbon steel
F HRX Well® hydraulic gradient	0.037

General Site Info	Value
Site Name	DoD-A
Site Location	0
Known contaminant type 1:	TCE, PCE
Known contaminant concentration (ug/L)	320
Treatment goals	
Percent reduction (%)	0.000
or	
Concentration (ug/L)	5
Tool setup	
Select contaminant category	TCE, PCE
Compatible media	ZVI
Media hydraulic conductivity (ft/d)	57
Media reactivity (min^{-1})	3.00E-03

Data Summary

The first block (Outputs from User Inputs gab) summarzies the well design based on the inputs in that tab. If the results shown are not practical input values can be adjusted where reasonable (i.e. aquifer hydraulic conductivity cannot practically be altered).

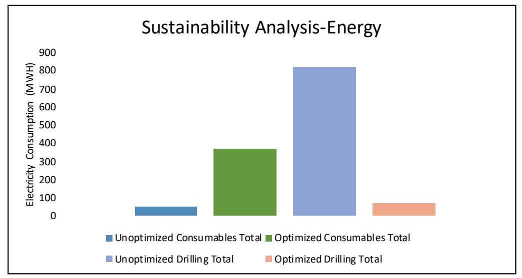
The second block will display updated values if mix-in media or a pump is added.

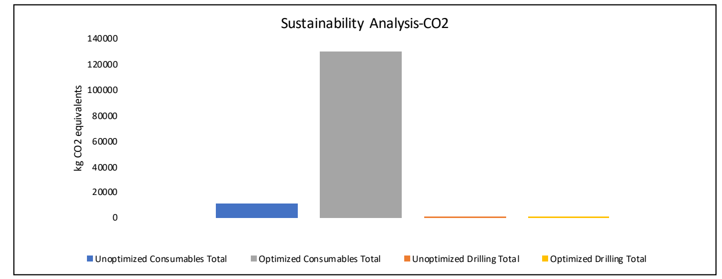
Outputs from User Input tab	Result
Well average capture width (ft)	43
Number of wells	1
Well HRT (days)	2.4
Contaminant HRT required (days)	1.0
Well length (ft)	973
Site is active or passive	Passive
Active pumping rate (gpm)	0.050
Cartridge length (ft)	10
Number of cartridges	19
Total capital cost **per well** (USD)	$469,493
Initial cost of reaction media (USD)	$26
Media changeout frequency (years)	0
Annual media changeout cost (USD)	30,000
Consumables total (kg CO_2 e)	10857
Consumables total (g NOx)	21230
Consumables total (g SOx)	31511
Consumables total (g PM10)	4292
Consumables total (MJ)	173178
Consumables total (MWH)	48
Annual media changeouts (kg CO_2 e)	0
Drilling total (kg CO_2 e)	846
Drilling total (g NOx)	10
Drilling total (g SOx)	954
Drilling total (g PM10)	8779
Drilling total (MJ)	1096
Drilling total (MWH)	818
Drilling for changeouts kg CO_2 e)	0

Results from mix-in media or added pump	Result
Well average capture width (ft)	43
Number of wells	1
Well HRT (days)	1
Well length (ft)	1949
Active pumping (gpm)	0.050
Cartridge length (ft)	10
Number of 10 ft cartridges	42
Total capital cost (USD)	$1,053,095
Total cost of reaction media (USD)	$0
Consumables total (kg CO_2 e)	129772
Consumables total (g NOx)	258648
Consumables total (g SOx)	351283
Consumables total (g PM10)	44618
Consumables total (MJ)	1342935
Consumables total (MWH)	373
Drilling total (kg CO_2 e)	69
Drilling total (g NOx)	1
Drilling total (g SOx)	77
Drilling total (g PM10)	713
Drilling total (MJ)	89
Drilling total (MWH)	66

Cartridge length (ft)	Number for initial well length
5	0
10	0

Cartridge length (ft)	Number for well length
5	85
10	42





Interpreting Sustainability Results

Example sustainability data and external comparisons are given in the table below to give context to sustainability data outputs.

The site had target plume width of 150 ft and target depth of 20 ft. The well was *450* ft long and the

Impact category for consumables	Associated CO_2 eq emissions (kg)	Associated NO_x Emissions (g)
Consumables emissions	496151	786333
Equivalent to driving n passenger cars per year	105	49730
Drilling emissions	5303	60
Equivalent to driving n passenger cars per year	1.1	3.8

Attachment G-4

Site C

Cell Key	Enter value	Select value	Calculated value	Required value to get capture width

Contaminant information

Enter:
1. Plume dimensions- Note that these are target treatment dimensions which may not be equal to the total plume. Plume length is not used in calculations. Instead, treatment length is calculated below using user-provided rate constants or those from the lookup tables.
2. Contaminant concentration- see below
3. Media porosity-This value should typically fall between 0.2 and 0.5
4. Treatment goals as percent reduction or a final concentration, including specific regulatory limits.

If treatability testing was not completed enter estimated values.

If more than one contaminant is present and part of the HRX Well(R) treatment plan do the following:
1. Enter one contaminant initial concentration and treatment goal. This can be in random order or address a primary contaminant of concern first. Note that known rate constants are entered in P32 or selected with media options in P35.
2. Take note of the resulting treatment and well lengths.
3. If two or more contaminants are present and part of the treatment plan repeat steps 1 and 2.
4. From the resulting well lengths use the longest treatment length to ensure the longest retention time required is achieved.

NOTE 1: Treatment lengths for two more more contaminants that are chemically dissimilar and or present in different concentrations should not be assumed correct without laboratoy verification from batch or column tests of the site groundwater containing the contaminants of concern.
NOTE 2: Use psuedo first-order rate constant for adsorptive media.

Site information

Enter values from site investigations and treatability testing. If information is not available use best estimates.

The HRX Well® hydraulic gradient should be assumed approximately equal to the aquifer hydraulic gradient. Item **F** on the adjacent diamgram show

Treatment media information

Enter data from treatability testing in M32, N32, and O32 will auto-fill.
If treatability testing was not completed select reference values from M35 and N35 (O35 will autofill).
Enter media density from known values or from Q2:Q13 in the Lookup Tables tab
Enter a media capacity value in M39. If the value is not known enter the partitioning coefficient and the capacity will be estimated using the concentration data provided above.
Enter media partition coefficient (measured or from literature) and the changeout freqeuncy will be calculated assuming changeout occurs at 70% of media capacity.

Active and passive sites

Active sites are those with hydraulic conductivity greater than 5 ft/d
Passive sites have hydrulic conductivity less than 5 ft/d
If site is active enter the gpm value from pumping tests.
Cell H8 under the Summary tab will display if the site is active or passive.
If sufficient capture is not achieved with the reactive media alone, a pump rate can be entered to increase capture width.
NOTE; That increasing flow rate into the well will cause well length to increase if reaction rates remain the same.

Explanation of mix-in media

Mix-in media was included in the design tool in order to optimize hydraulic conductivity (and related parameters) in the cartridges. These media are not reactive but it should be noted that using too much will reduce the total available surface area of treatment media. The mix-in media are useful when hydraulic conductivity is too high or too low for the treatment media. In these scenarios the retention time determined from reaction rate constants may not be achieved. Changing the hydraulic conductivity in the cartridge is one method of specifying the cartridge retention time.
Note that the weighted media hydraulic conductivity is an *estimate* only. For a thorough analysis refer to HydrogeoSieveXL2 (http://people.ku.edu/~jfdevlin/Software.html)

Well parameters

Select HRX Well® diameter.
The remaining values are automatically calculated in a separate tab and returned here.
A reference diagram is provided to the right- match letters next to input cells to diagram.
The cartridge diameter is assumed to be 2 inches less than the HRX Well® diameter.
Enter well hydraulic gradient. The value should be approximately equal to aquifer hydraulic gradient.

Tool input description	Value
General Site Info	
Site Name	DoD-C
Site Location	
Known contaminant:	TCE, 1,4-dioxane
Contaminant information	
Target treatment width (ft)	185
Target treatment depth (ft)	10
Initial contaminant concentration (ug/L)	300

Treatment goals	Value
Percent reduction (%)	
or	
Concentration (ug/L)	5

Aquifer Properties		Value (secondary units)
Enter site hydraulic conductivity K (cm/s; ft/d)	5.00E-05	0.142
Enter site hydraulic gradient i	0.055	
Enter aquifer thickness b_a (ft)	5	
Enter site transmissivity T (cm^2/s; ft^2/d)	0.008	0.709

Enter or select contaminant and media values

Contaminant	Media	Media hydraulic conducitvity (cm/s)	Media hydraulic conducitvity (ft/day)	Enter $k_{contaminant}$ (min^{-1})	Calculated half-life (days)
TCE, 1,4-dioxane	ZVI	0.1	283	3.00E-03	0.2

Contaminant	Select	Media hydraulic conducitvity (cm/s)	Media hydraulic conducitvity (ft/day)	$k_{contaminant}$ (min^{-1})
Select	Select	#N/A	#N/A	#N/A

Enter treatment media porosity n	0.35
Enter media density value (kg/m^3)	2100
Media capacity (mg/kg)	
Media K_d (L/kg)	
Enter cost per kg of treatment media	$1.64

Select "Active" if the site will use a pump	Passive
If active, enter gpm value	

Select mix-in media	Mix-in media K (cm/s)
Gravel	3.00E+00

Enter % of mix in media	Percent reaction media (%)
0.00%	100.00%

Weighted K_{media} (ft/d)	283

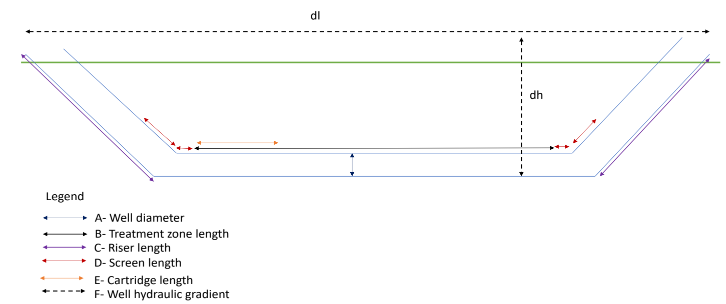
Well parameters	
A Select HRX Well® diameter (in)	8
B Minimum treatment zone length (ft)	106
C Riser length (ft)	100
D Total screen length (ft)	218
Total HRX Well® length (ft)	423
E Number of 10 ft cartridges	13
Drill time (Hrs)	36
Select well casing material	Carbon steel
F HRX Well® hydraulic gradient	0.055

Unit Conversions

Enter hydraulic conductivity in ft/d to get value in cm/s	
Hydraulic conductivity in cm/s	0
If concentration is in molar units enter value	
Enter contaminant molecular weight	
Concentration in ug/L	0

Other helpful conversion factors

	86400 seconds
1 foot	30.48 cm
1 gpm	192.5 ft^3/d
1 gallon	3.785 L
PPT	ng/L
PPB	ug/L
PPM	mg/L



General Site Info	Value
Site Name	DoD-C
Site Location	0
Known contaminant type 1:	TCE, 1,4-dioxane
Known contaminant concentration (ug/L)	300
Treatment goals	
Percent reduction (%)	0.000
or	
Concentration (ug/L)	5
Tool setup	
Select contaminant category	TCE, 1,4-dioxane
Compatible media	ZVI
Media hydraulic conductivity (ft/d)	283
Media reactivity (min^{-1})	3.00E-03

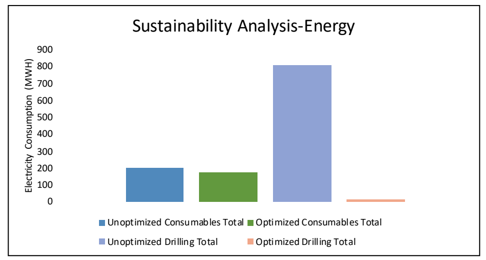
Data Summary

The first block (Outputs from User Inputs gab) summarzies the well design based on the inputs in that tab. If the results shown are not practical input values can be adjusted where reasonable (i.e. aquifer hydraulic conductivity cannot practically be altered).

The second block will display updated values if mix-in media or a pump is added.

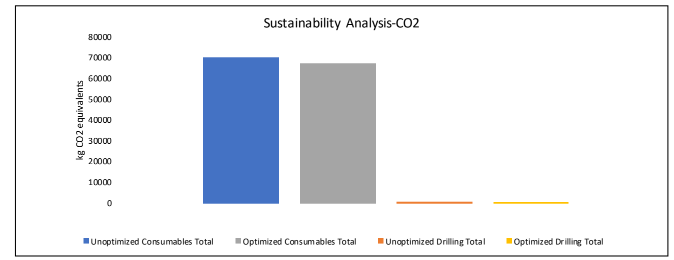
Outputs from User Input tab	Result
Well average capture width (ft)	79
Number of wells	3
Well HRT (days)	2.4
Contaminant HRT required (days)	0.9
Well length (ft)	423
Site is active or passive	Passive
Active pumping rate (gpm)	0.000
Cartridge length (ft)	10
Number of cartridges	6
Total capital cost **per well** (USD)	$293,232
Initial cost of reaction media (USD)	$4,412
Media changeout frequency (years)	0
Annual media changeout cost (USD)	30,000
Consumables total (kg CO_2 e)	70160
Consumables total (g NOx)	111035
Consumables total (g SOx)	152800
Consumables total (g PM10)	19623
Consumables total (MJ)	703437
Consumables total (MWH)	195
Annual media changeouts (kg CO_2 e)	0
Drilling total (kg CO_2 e)	835
Drilling total (g NOx)	9
Drilling total (g SOx)	941
Drilling total (g PM10)	8666
Drilling total (MJ)	1082
Drilling total (MWH)	808
Drilling for changeouts kg CO_2 e)	0

Cartridge length (ft)	Number for initial well length
5	21
10	11



Results from mix-in media or added pump	Result
Well average capture width (ft)	79
Number of wells	3
Well HRT (days)	1
Well length (ft)	231
Active pumping (gpm)	0.000
Cartridge length (ft)	10
Number of 10 ft cartridges	4
Total capital cost (USD)	$173,533
Total cost of reaction media (USD)	$0
Consumables total (kg CO_2 e)	66946
Consumables total (g NOx)	104885
Consumables total (g SOx)	142439
Consumables total (g PM10)	18090
Consumables total (MJ)	624467
Consumables total (MWH)	173
Drilling total (kg CO_2 e)	15
Drilling total (g NOx)	0
Drilling total (g SOx)	17
Drilling total (g PM10)	161
Drilling total (MJ)	20
Drilling total (MWH)	15

Cartridge length (ft)	Number for well length
5	8
10	4



Interpreting Sustainability Results

Example sustainability data and external comparisons are given in the table below to give context to sustainability data outputs.
The site had target plume width of 150 ft and target depth of 20 ft. The well was *450* ft long and the

Impact category for consumables	Associated CO_2 eq emissions (kg)	Associated NO_X Emissions (g)
Consumables emissions	496151	786333
Equivalent to driving n passenger cars per year	105	49730
Drilling emissions	5303	60
Equivalent to driving n passenger cars per year	1.1	3.8