DESIGN CONSIDERATIONS FOR FULL-CYCLE WATER MANAGEMENT SYSTEMS

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ABSTRACT

Water production occurs throughout the life of oil and gas wells. As the oil and gas fields mature, water production becomes even more prevalent. Managing this water has and will continue to become a larger part of the oilfield's considerations. This paper takes an in-depth look at the design criteria for planning and building successful full-cycle water management systems, and specifically at salt water disposals batteries, produced water gathering systems, fresh and recycled water pits, and water cleaning technologies available to the engineer.

INTRODUCTION

The recycling of produced water does not always make economic sense and cannot last forever. No matter the field or basin, the drilling and fracture stimulation of new wells will ultimately come to an end. However, every well, that has a reasonably long life, will produce water that eventually must be injected into the ground, either for waterflood support or as waste water. Because there will always be injection and disposal, it is the industry's responsibility to ensure that disposals do not impact freshwater resources (above and below the surface), negatively impact the environment, or create seismic events. Regardless if the disposal is private or commercial, it is the operator's responsibility to guarantee all casing strings are properly cemented to the surface and verified by a bond log. The operator must also make sure that the mechanical integrity of the wellbore is continually maintained, and not just to the minimal state regulations. Moreover, the operator must see that every disposal well is operated ethically. This is done by constantly monitoring annular pressure, keeping injection pressures below the fracture gradient, injecting into permitted zones, and simply not over injecting.

The guidelines outlined below may be used for creating a greenfield full-cycle water management system, or when adding to, or expanding, an existing system. The following topics will be investigated:

- Vendor Owned / Managed versus Company Owned / Operated: In today's business environment, determine what makes the best sense for your company and its use of capital resources.

- System Capacity and Layout: Evaluate for current and future needs. Design for the maximum amount cases. Build the system above current volumes and determine what expansion will be required for the future drilling program.

- Pipeline Material and Sizing: Determine the operating pressures, surface injection pressures, water corrosiveness, and environmental concerns. Companies must also keep in mind the cost to buy and install the selected pipeline.

- Recycling Pit Sizing and Construction: Must define what the goals and needs are with respect to water quality and total water volume.

- Pump Selection and Other Equipment: Determine which type and size of pump is needed to optimize profitability and efficiency. Consider where to install ESD valves, back pressure valves, and check valves.

- Settling Time and Tank Storage Volumes: Design for predicted volumes and potential injection downtime, water quality, and oil-carryover.

- Water Compatibility, Scale, and Chemicals: Analyze and understand water scaling tendencies and compatibilities of produced water, fresh water, and vendor fracking chemicals.

THIRD PARTY VS. COMPANY OWNED DISPOSAL WELLS

Today there are essentially two options when trying to dispose of water. A company can choose to use a third party (commercial) disposal or can build their own privately operated disposal. To decide which option to use, the engineer must fully understand the goals of management and what makes fiscal sense for meeting these goals.

By selecting the third party (commercial) disposal option, the company will benefit from reduced environmental exposure, fewer employees, and less capital outlay (more resources for the drilling program). The downside is higher lease operating expenses (than if company owned) and production downtime arising from interruptions in the third party service. If the company is a smaller private equity that is operating in a short term “buy, develop, and sell” mode, then the third party option is likely the better choice. Lease operating expenses will be higher; however, the capital for building the water system can be deployed on drilling projects that should have a higher rate of return, and will increase recoverable reserves.

Following the company owned and operated route, the operator will enjoy a 30-50% reduction in water handling expenses, an incremental increase in well life, and a competitive advantage over other operators in the area. The main disadvantages are increased environmental exposure, the burden and cost of additional employees, and the diversion of capital from the drilling program. If a company is a large E&P with ample resources in the ground and bank, then it likely makes more sense to design and build their own private disposal. These companies are always looking to gain competitive advantages on their peers, and this is one method of accomplishing this goal.

While not listed, there is always a third option…a hybrid where the operator and water logistics vendor form a partnership and share costs and operational responsibilities. The possibilities are endless, and can be structured in a multitude of ways. The important part of any partnership, is that both sides benefit to their mutual satisfaction.

SYSTEM CAPACITY AND LAYOUT

The first step in designing and building a salt water disposal system is determining the pipeline sizing and layout that will best accommodate the water production in the field. It is important to have accurate water production forecasts, along with timing of new drills. Planning for the future is key to the long term profitability of the water management system. This is accomplished by having knowledge of rig schedules and quality type curves for water production from wells in the drilling program. Design on the known, but be sure to plan and accommodate for the future. Determine the maximum possible water volume, then design and build for this capacity.

The engineer may question the economics of building for the maximum rate (or close) versus the sustained rate later in the wells life. An analysis would show that the majority of the water is recovered upfront during flowback and the first 2-3 years of the life of the well. Hauling this water would burden the well with high lease operating expenses, severely reducing the rate of return on the well. For a graphical representation, see Figure 1. A full-blown water management system would not be constructed for a single well, but this cost savings is compounded when drilling a complete development program. Keep in mind the cost to build a system is not a linear relationship with well count and decreases dramatically on a per well basis.

The available pipeline capacity from declining water volumes are replaced by the new wells as they come on line. For a graphical representation of a small drilling program, see Figure 2. The total water volume continues to increase even as only one well per month is brought on line. Water volumes will plummet when the drilling stops, but the cost savings of piped water versus hauling will have paid for the system, and then some.

Another important element to an efficient water management system is the layout and location of the disposal wells. Work with the land department or land consultants who possess a strong working knowledge of the area. They can assist with determining the optimal location for the disposal well(s). Regardless if the engineer is designing and building an entire disposal system or just one disposal well, the location of the initial SWD should be in a centralized location, close to electrical and highway infrastructure. Placement of subsequent SWDs are a function of reservoir injectivity, system efficiency, and minimizing pipeline costs (five miles of large diameter pipeline can fund an additional SWD).

The next phase is to add pipelines to the system. These lines gather water either for disposal or recycling, but should run through the SWD tank battery first to extract carry-over oil. Pipeline right-of-way can be complicated, as it often crosses multiple landowner's property. Learn which landowners are easy to work with and which ones are difficult to work with, then avoid the difficult ones. To facilitate the permitting and construction processes, know the terms of the surface use agreement and start the right-of-way permitting early and where possible, permit all lines together in one right of way (water transfer, electric power, oil and gas gathering). If dual pipelines are being considered (the second initially for transfer of clean water, then produced water gathering, later), permit it at the same time. This will save time and money on land and surveying services.

To build a successful gathering system, the engineer must take into consideration the proximity of the producing wells, the roads in the area (provides easy access and allows for daily inspections), and property boundaries. Avoid road bores and road crossings, as they increase costs and can disrupt operations. GIS programs are extremely helpful when designing the pipelines and can help corroborate the project's design.

Effectively designing a full system in advance is close to impossible, as there are many dynamics that surround the implementation of a full cycle water system...changing drilling schedules and stimulation schedules, water volumes not matching type curves, regulatory requirements, landowners, etc. The key to successful adaptation is to always leave a place for expansion. This means adding a tee, a valve, and blind at any point in the system that may have need for a tie-in. When laying a pipeline, always place a tee, valve, and blind every half mile or so. This provides tie-in points or, more importantly, looping points for secondary lines, should the first line end up too small.

PIPELINE MATERIAL AND SIZING

Materials

When selecting pipeline materials, the factors to consider are what the operating conditions will be, what are the required operating pressures and how temperature affects MAOP (maximum allowable operating pressure), the materials' resistance to corrosion, the expense to purchase and install the pipeline, and the environmental concerns associated with the different pipeline material options.

Polypipe is a common material that is frequently chosen in water gathering and transfer systems. The advantages of polypipe are that it is non-corrosive internally and externally, no cathodic protection is required, no welding is required, it is extremely durable and semi-flexible, and available in many sizes ranging from 1" to 24" in SDR7. SDR7 is preferred, as it has the thickest wall and generally provides the most protection from spills. Polypipe is quick to assemble and is generally more economical versus other pipeline materials. The disadvantages of polypipe are that its MAOP is limited to 250 psi at 73° F with SDR7 pipe and declines quickly with increasing temperatures. Polypipe also has a large coefficient of expansion and contraction, which can cause complications when used above ground.

Steel is another common pipeline material and like polypipe, there are advantages and disadvantages associated with it. Steel has an excellent MAOP and because of that, is the material of choice in areas with large elevation changes. Steel is also extremely durable, has a low coefficient of expansion and contraction, and is available in sizes ranging from 1" to 36". Accordingly, steel is a practical choice in almost all environments. The disadvantages of choosing steel are that it must be externally coated or wrapped and should also be internally coated. That can be incredibly expensive depending on the length and size of the pipeline. Steel is also expensive to buy, transport, and assemble as it has to be welded.

Fiberglass is also an option to consider when choosing pipeline material. Similar to steel, fiberglass has a wide range of MAOP and is another solid option in areas with large elevation changes. Fiberglass also has a low coefficient of expansion and contraction, no cathodic protection is needed, and is available in sizes from 2" to 36". Fiberglass is also non-corrosive and requires no welding, which means it is faster to install than steel. The disadvantages are that fiberglass should be buried and is generally more expensive than steel.

There are numerous composite pipe materials available on the market, each with its pros and cons. This pipe is usually higher priced than polypipe, requiring special fittings and service personnel to install, but has a higher MAOP than polypipe. It is the engineer's responsibility to weigh the benefits and decide whether to use these products or not.

Sizing

"Pipelines are always too large or too small…they are NEVER the right size." ………unknown

A simple statement but so true. It is the author's recommendation to error on the side of "too large", as the consequences are higher operating pressures, reduced capacity, and worse, the increased risk of pipeline rupture.

There are numerous software packages for modeling pipelines, although they are expensive and cumbersome to use, as most are designed for multi-phase flow and require well deliverability. Accurate designs may be achieved using a spreadsheet, applying either the Darcy-Weisbach equation or the Hazen-Williams equation.

The Darcy-Weisbach equation is a phenomenological equation derived for incompressible liquids. It requires determination of the flow regime and the Darcy friction factor (based on diameter of the pipe, the roughness height, kinematic viscosity of the fluid, and the velocity of the fluid). Its use is recommended when calculating losses for slurries and incompressible fluids that are out of the norm for oilfield applications.

The Hazen-Williams equation is an empirical equation derived for water systems by Allen Hazen and Gardner Williams. It eliminated calculating the Darcy friction factor by employing a coefficient that is not a function of velocity. However; its disadvantage is that it does not account for the effects of temperature. Because temperatures in oilfield water gathering systems normally range from 65ºF to 140ºF, the impact is negligible. Even though engineering calculations never exactly match field conditions (for a plethora of reasons), it is widely accepted for use in designing fire sprinkler systems, water supply networks and irrigation systems. There are numerous tables in literature that provide the Hazen-Williams coefficients of most piping materials. While published coefficient value for polypipe is 150, the author has, from filed measurements, found a coefficient of 140 is more appropriate for polypipe, perhaps due to the beads that are formed at fusion bonds, or that many oilfield waters are heavier than fresh water.

When constructing a model, begin by laying out the path of the gathering or transfer system on a mapping program that can provide elevational cross sections. Starting at the delivery point, where volumes are highest, work outward to the source points. Break the pipeline into segments with a condition change as the endpoint. Then that endpoint becomes the starting point for the successive segment(s). Examples of an endpoint are where there are tees (volumes decrease), or at elevational high or low points (where head pressures go to zero or are at their peak). Use the Hazen-Williams equation to calculate the frictional loss, then add in or subtract out head pressure due to the fluid weight. The pressure at the endpoint, becomes the starting pressure for the next section as you work outward. See Figure 3 for an example of pipeline segmentation.

The engineer must understand that sizing is not based on a snap-shot of volumes in time. For example, assume a main trunkline brings in water from a new block of acreage, which has two laterals, each gathering from a large group of wells to be drilled (east side and west side). Further to this example, the drilling schedule calls for drilling a large portion of the wells on the west side, then move to the east side. Both the east and west laterals should be sized for the maximum volume to be realized, but the main trunkline should only be sized for the east side maximum, plus the predicted water rate of the west side at the time of the east side's peak (possibly 6-12 months after the last west side well was fracked). If the engineer sizes the main trunkline (downstream of the two laterals) for the total of the peak rates, he/she may waste a significant amount of capital as large bore pipe is so expensive to purchase and install.

FRESH WATER / RECYCLED WATER PIT SIZING AND CONSTRUCTION

Pit Sizing

Determining the size of the pit volume is a simple matter of calculating the balance rates and volumes between the needs of the frack crews and the deliverability of the source water, be it fresh or produced.

Example: Triple Y Oil Company has two frac crews running on pads a mile apart. Each frac crew can pump four 10,000 bbl stages per day, and there are 48 stages per pad to pump. The fresh water wells can produce a total of 35,000 bbl per day, and the water cleaning company can provide 20,000 bbl per day from the produced water gathering system.

Water Needs:	12 days per crew-pad / 80,000 bbl per day / 960,000 bbl total
Water source:	55,000 bbl per day / 660,000 bbl in 12 days
Difference:	300,000 bbl
Pit size:	350,000 - 360,000 bbl excess for evaporation and pit bottoms

The maximum allowable size of a pit is 500,000 bbl, unless built in tandem and separated by berm wall meeting engineered standards, discussed in the next section.

Construction

The University Lands of Texas website offers excellent guidelines for the construction of a produced / recycled water pit. The following is the URL of their “Produced Water Frac Pit Application, Design, Construction, Operation, and Closure Specifications” document:

http://www.utlands.utsystem.edu/Content/Documents/Operations/Prod_Water_FracPit_Specifications.pdf

This document is fashioned after EPA guidelines and gives specifics to site selection, which is dictated by the distances to water wells, housing, churches, hospitals, water ways, highways, plugged and abandoned hydrocarbon or water wells, and geological structures. It also provides guidance on the composition of the soil below the proposed pit, and the sampling that is required for determining the baseline, prior to construction.

Berm material and construction for produced / recycled water pits is fairly straightforward. "The soil used in the embankment (berm) shall be free of foreign material such as rocks larger than four inches, trash, brush, and fallen trees…The soil used in embankment shall be constructed in lifts or layers no more than eight inches compacted to six inches thick at a minimum compaction effort of 95% Standard Proctor Density (ASTM D698) at - 1% to +3% optimum moisture content…The embankment walls shall be stabilized to prevent erosion or deterioration." More details can be found in the document, referenced above. The slope of the berm walls is dependent upon whether it is an interior wall (water side) or an exterior wall. The interior slope cannot exceed a ratio of 2H:1V, or 26.6 degrees, and the exterior wall must be less than a ratio of 3H:1V, or 18.4 degrees.

Specification for liner materials are detailed in Section 8 of the University Lands Guidelines, referenced above. Two liners and leak detection are required. University Lands Guidelines define primary liner material, secondary liner material, anchor trenching depth, and testing / location of thermally welded seams. In addition, the UL Guidelines provide what is required with respect to the construction of the leak detection sump, monitoring frequency and record keeping.

PUMP AND OTHER EQUIPMENT SELECTONS

There are several types of pumps and ancillary equipment to consider when designing and building an economical and efficient disposal system.

Positive displacement (PD) pumps are the most common pump used in the field. They are very reliable, easy to maintain and are the most efficient of the pump options. Moreover, PD pumps have possibly the best pressure ranges and a reasonable volume range, up to ~7,000 bpd. Their sizing is very accurate, as they move a specific amount of fluid per stroke. The disadvantages typically associated with PD pumps are that rod oilers and vibration leaks can cause minor spills. Finally, they require frequent maintenance, which ultimately increases the operating expenses.

Horizontal pumps are another viable option to look at when evaluating a disposal system. These pumps are essentially just an electric submersible pump (design for producing wells) laid over on its side. Horizontal pumps have good pressure ranges, and the volume ranges can be taken up to 10,000 bpd. Horizontal pumps are also cleaner than PD pumps, thus require less maintenance and upkeep on them. However, they are far less efficient than PD pumps and have high upfront costs, which can make them hard to justify for lower volume/pressure projects. Additionally, they are prone to failure due to the oscillation of the thin, long axial shaft upon which the impellers are mounted.

Axially split case pumps are an excellent option to consider when dealing with high volume, medium range pressure projects. They have a large pressure range and essentially an unlimited volume range, and can deliver a fine tuned volume when coupled with a variable speed drive. They are a very clean pump, and require minimal maintenance. When maintenance is required, a specialized technician is essential. These pumps have a very high per unit cost and have a long lead time.

There are other pieces of equipment to consider when designing and building a pipeline disposal system. One important decision is whether to use a variable speed drive or "soft-start" on the pump's electric motor. Both cost about the same, so it truly comes down to what device fits best in the system. Variable speed drives allow the operator to fine tune pump volume rates, but typically can be expensive to repair. Soft-starts minimize the amperage surge experienced when motors first start up, thus minimizing power requirements and lowering peak demand (saving money on electrical power). They usually require little maintenance. Again, deciding between these two options comes down to preference and what makes the most sense for the disposal and pipeline system.

Check valves, back pressure valves, and motor valves are all integral parts of a successful disposal and pipeline system. Check valves are necessary to prevent back flow of water within the pipeline, caused by elevation changes. Back pressure valves can be utilized to prevent siphoning of the tanks and also over-speed of transfer pumps, preventing motor failures. Motor valves are essential to have in order to shut off water flow to the SWD tank battery, which avoids running the tanks over. Lastly, depending on the quality of water that is being cycled through the disposal system, companies may want to consider filters that help manage the solids that inevitably are introduced to the tank battery system or injected into salt water disposals. A witch's hat filter (y-strainer), pod filter, and amiad filter are all dependable and proven solids management options.

SETTLING TIME AND TANK STORAGE VOLUMES

Separating oil and settling out the solids from the produced water prior to injection has been an issue since the inception of salt water disposal. Unfortunately, there is no definitive answer for the amount of time or configuration required to allow for the solids to separate from the oil and water; however, most field personnel and engineers agree that more time is better. In general, SWD tank batteries consist of four types of tanks: settling tanks, gun-barrels, suction tanks and skim oil tanks. Optionally, a fifth tank type is included, the sand trap tank. The most common configurations are, beginning at the inlet:

1. Sand Trap Tank (optional), Settling Tanks, Gun-Barrel, Suction Tanks, with Oil Tanks to the side
2. Gun-Barrel, Settling Tanks, Suction Tanks, with Oil Tanks to the side

In Design 1, a transfer pump is required to move water and oil from the settling tanks to the gun-barrel. In Design 2, no transfer pumps are required. See Figures 4 and 5 for simple schematics of these designs.

Sand Trap Tank

This tank's function is simply as stated. It traps the high density solids up front, keeping them out of downstream settling tanks, and reducing the number of times that the settling tanks need to be cleaned out. The tank has top inlets and outlets, so no pumping is required to move fluid to the settling tanks. The author has never seen a sand trap tank used in the second design.

Settling Tanks

The purpose of the settling tanks is to provide quiet time (low fluid velocity) to allow solids to fall out of the fluids. The first design has settling tanks upstream of gun-barrel tanks, giving the oil, water and oil/water emulsion time to drop solids. This does result in cleaner oil going to the gun-barrel. Because the oil and water are transferred to the gun-barrel by pump, the volume in the settling tanks fluctuates, oscillating the length of quiet time for solids settling. With the second design, the majority of the oil is removed prior to the settling process, and may need further cleaning to facilitate sales. Because the settling tanks gravity-feed to the suction tanks, they stay at a constant level providing maximum settling time for solids to fall out of the water. There is no magic number for the amount of settling tanks in the disposal system, though tank modifications that provide weiring have proven to enhance the process. Another popular way to separate solids is by utilizing angled inlets, which can be used in combination with weired tanks. As the disposed water comes into the settling tanks, the angled inlet creates a centrifugal effect which pushes the solids to the outer edge of the tank where they fall to the bottom of the tank and separate out. Chemicals are another option when attempting to separate solids.

Gun-Barrel Tanks

The gun-barrel tank is where the true process of separating oil from the water occurs. Location pros and cons were discussed in the settling tank section, above.

Suction Tanks

The suction tanks serve two purposes: reduce the number of times the injection pump cycles, and provide storage in an emergency downtime event. Simply put, the more volume that is available between pump starts and stops the easier it is on the pump equipment. The author recommends 100 barrels of storage tank per 1000 barrels of throughput per day. Storage volume may also provide a buffer, when a pump or well failure results in a cessation on injection, giving an operator time to respond to the problem.

Oil Tanks

These are normal oilfield oil tanks that receive overflow of oil from any of the settling or suction tanks, and where the gun-barrel delivers its oil when in operation.

To optimize oil separation and solids separation, it is recommended to analyze the water several times, at different points, over a few weeks. The most beneficial tests that can be performed are TDS (total dissolved solids), TSS (total suspended solids), oil carry-over and water millipore. TDS and TSS are measured in milligrams per liter and provide a measure of actual material in the water. Oil carry-over is measured in parts per million, and should be below 10, if the system is functioning properly. The millipore test is a qualitative test that provides an indication of the filter cake, created by solids, which can buildup on the reservoir face. This research, which should be performed at least quarterly, will provide a company with an overall measure of the tank system's effectiveness. The author feels chemicals should be a last resort and only used when mechanical processes fail, as they only treat the symptom and do not provide a cure.

WATER COMPATIBILITY, SCALE, AND CHEMICALS

Understanding water scaling tendencies, compatibilities of produced water, fresh water, and vendor fracking chemicals is paramount to keeping the disposal system in working order. If a disposal system develops scale, then analyze the issue and rapidly work to a solution. Familiarity with the produced water's chemistry (total dissolved solids), the degree of the microbial infestation, and scaling tendencies are paramount to successful, sustained disposal. Be sure to always let the pipelines, tanks, and pumps dictate what treatment to use. Do not immediately choose the most economic or simplistic method, as that often worsens the problem. The operator must have in-depth knowledge on treatments and be capable of selecting the best treatment for the issue. If scaling or microbial issues exist, if it is possible, the production tank battery is the preferred place to treat. It has the least amount of fluids to treat, and once the problem is resolved, it should no longer be a concern downstream. An important point to keep in mind is that while water tests may indicate scaling tendency, it does not mean that the scale will precipitate. The presence of physical scale is when treatment is justified.

There are three common types of scale: calcium carbonate, calcium sulfate, and barium sulfate. The easiest to deal with is calcium carbonate, as it is acid soluble and easily dissolved. Calcium sulfate is more difficult to treat. It must first be converted to calcium carbonate using a scale converter, and then dissolved with acid. Barium sulfide is the bane of the oil industry, because once formed, only a hammer and chisel are effective on removing it.

CONCLUSION

The value of implementing full-cycle water management in a development program is realized by eliminating the high cost of trucking at the beginning of the flowback period and first two years of a well's life. This is often where over 50% of total water production occurs. In addition, costs savings are enhanced by purchasing less fresh for fracture stimulation and its associated trucking, the reduction of cycle time that can be extended by water sourcing delays, and the increase in the value of the asset through lower lease operating expenses and longer well life (increasing recoverable reserves).

There is not a fits-all solution or a single design for a full cycle water management system. Each project is unique, although common threads can be found between all of them. The purpose here was to introduce the engineer and field personnel to the options available, and to provide a guide to designing and equipping the system. The main takeaways are that numerous solutions exist for each part of the system, that no system can be designed in its entirety in advance, and, most importantly, always leave a place to expand.

Figure 1 - Water Production for One Well

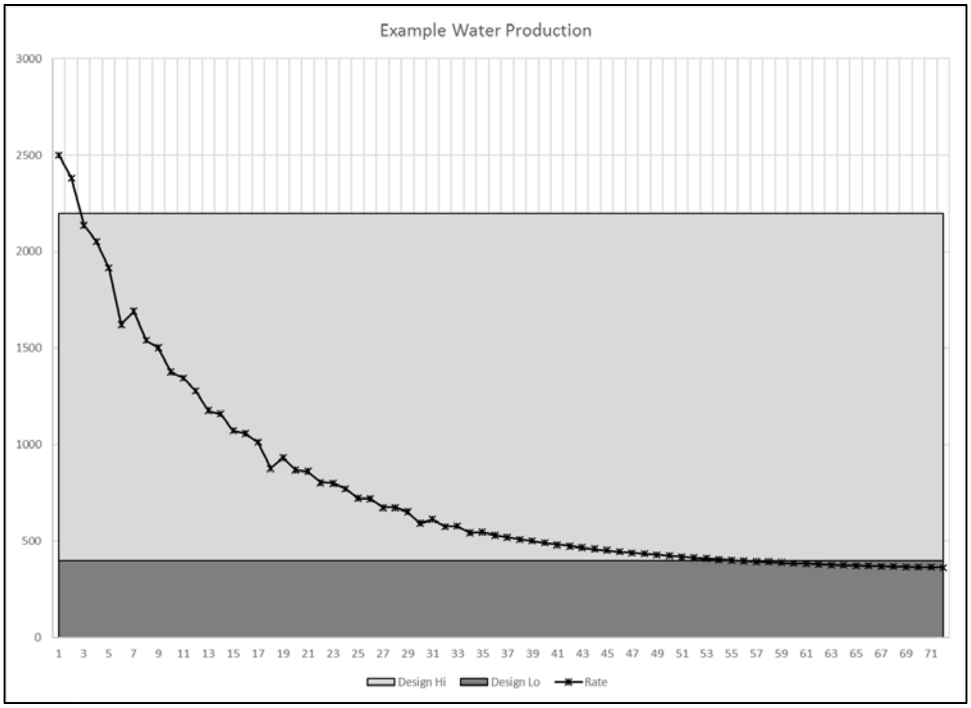


Figure 2 - Water Production in a Development Program (using same volumes as shown in Figure 1)

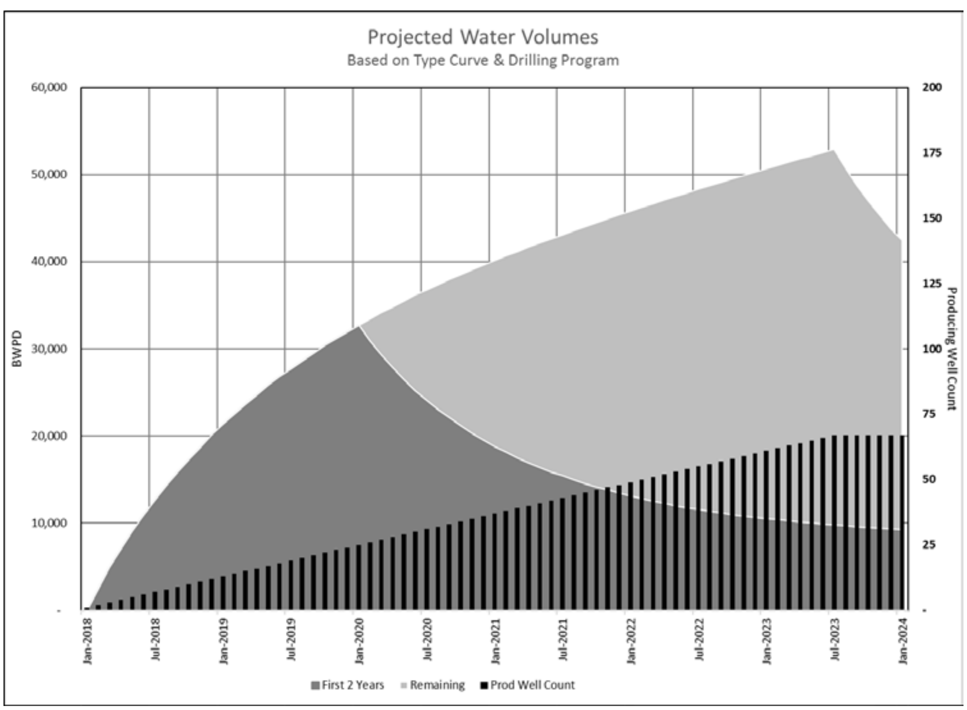
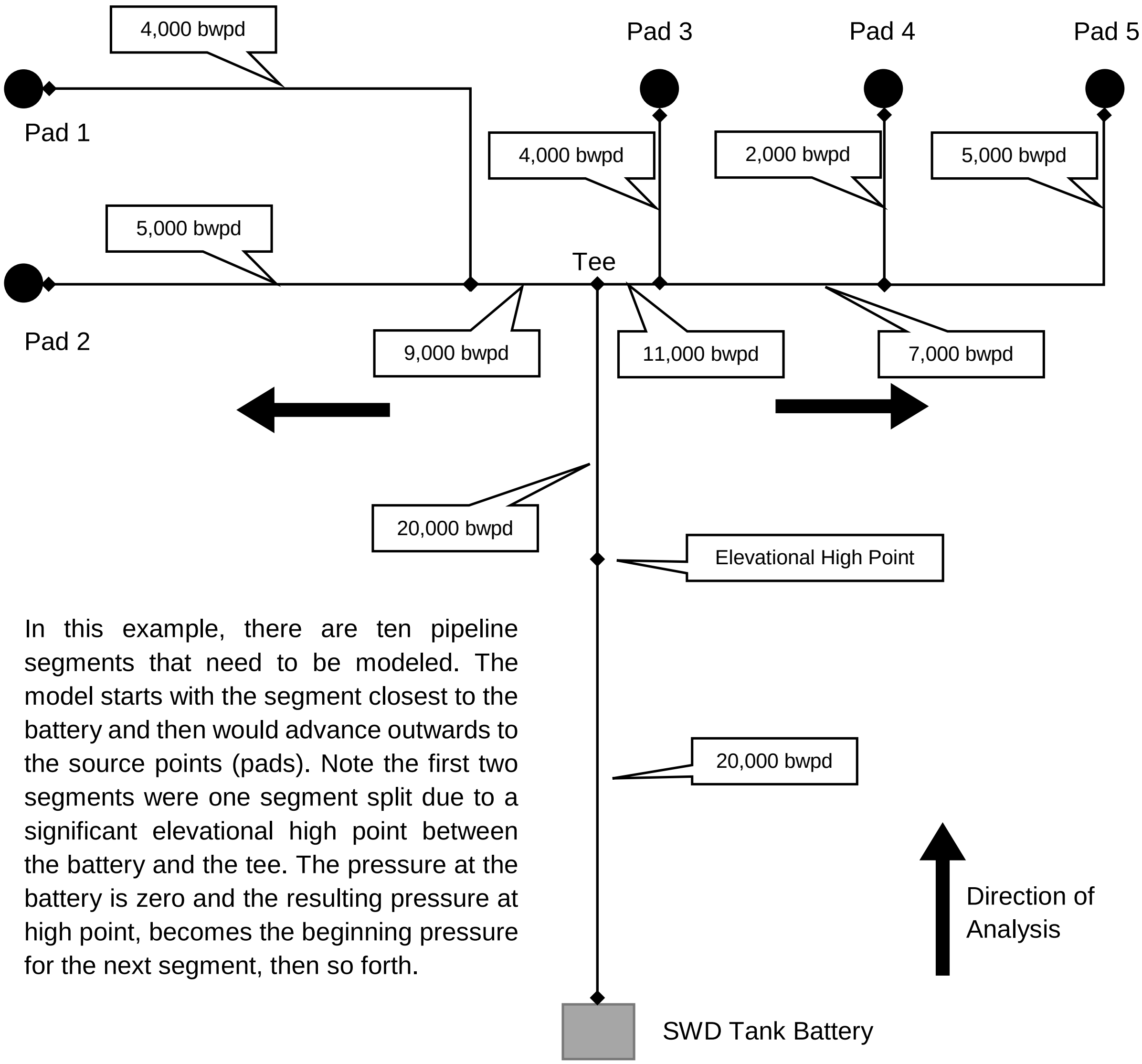


Figure 3 - Segmenting Pipelines for Analysis



In this example, there are ten pipeline segments that need to be modeled. The model starts with the segment closest to the battery and then would advance outwards to the source points (pads). Note the first two segments were one segment split due to a significant elevational high point between the battery and the tee. The pressure at the battery is zero and the resulting pressure at high point, becomes the beginning pressure for the next segment, then so forth.

Figure 4 - SWD Tank Battery - Design #1

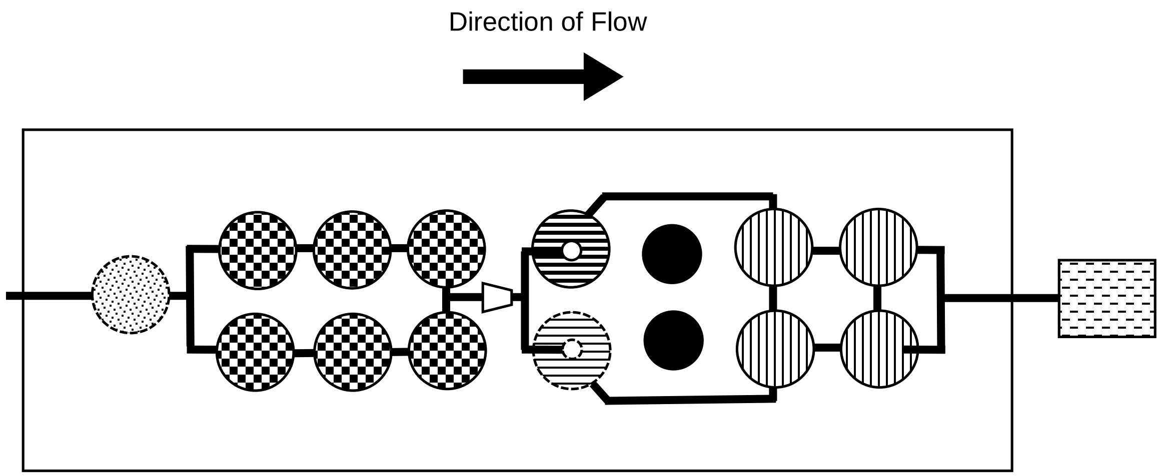


Figure 5 - SWD Tank Battery - Design #2