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EconoPure™ Water Systems

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# DEMWAX II

(Patent Pending)

## Second Generation Depth Exposed Membrane for Water Extraction (DEMWAX™) for seawater and brackish water desalination

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## Introduction

The Depth Exposed Membrane for Water Extraction (DEMWAX™) is a novel approach to both fresh surface water treatment and seawater desalination that deploys a system directly within the source water body, utilizing the natural pressure that exists at depth. DEMWAX II, a second generation of the original system, brings this natural pressure based system onshore, providing the similar type of energy savings without the disadvantages of offshore operation. Unlike the original DEMWAX it is not dependent on ocean depth in its immediate vicinity and so has worldwide ocean-side applicability. This configuration has many advantages over the incumbent technologies. The base technology is patented and other associated patents are pending. This paper provides detail on the DEMWAX II system and its comparative advantages.

## Basic Theory

The idea behind the DEMWAX II™ system is harnessing natural water pressure (hydrostatic pressure from water depth) to drive a reverse osmosis process in lieu of artificially created pressure. The system employs membranes where natural pressure can be created in deep well bores. Water movement is created by bringing in feed water through an upper ocean pipe and out through a lower ocean pipe, passing through membranes at the bottom of an internal open tube in the well bore. The DEMWAX II system has many applications (see discussion below) but the two primary applications are the desalination of seawater and the treatment of brackish or fresh water inland.

For both primary applications, there are four basic premises or design traits behind the technology.

1. Natural water pressure variable in amount: Well bores of increasing depths provide increasing pressure accommodating characteristics of both existing source water and required product water specifications.
2. Atmospheric pressure communication: Communication of atmospheric pressure to the membrane permeate collection tube allows the natural creation of the pressure differential needed for the process. This differential is maintained by pumping the permeate water to the surface.
3. Water movement: All membrane processes require the movement of feed water to the membrane surface and removal of the concentrate or brine. Membrane in the DEMWAX II system are designed so that gravity and small pump lifts remove any concentrate and brings more water to the surface of the membranes. The spacers between the membranes are at least 3 times those used in traditional SWRO configurations allowing for an uninterrupted flow of water between them.

4. Low flux: Membrane flux (produced water per unit of membrane area) is often associated with system efficiency in traditional systems. That is, higher flux means less pre-treatment costs, less membrane, fewer pressure vessels, etc. However, higher flux also means higher transmembrane pressure and higher velocities into the membrane face. Low flux, on the other hand, reduces the driving pressure requirement. Low flux also reduces stress and fouling on membranes increasing the effective life and reduces particulate fouling.

**New Paradigm**

Most research in seawater desalination has focused on reducing the energy requirements, as that remains the largest cost component of desalination plants today. There are physical limits in energy required for separating dissolved ions from water and these limits bound the efficiency gains that are available. For any membrane desalination process the recovery rate (ratio of permeate to feedwater volumes) dictates the energy requirement as it defines the concentration of the water fed into the system and the required separation energy is proportional to concentration of a solution, in this case salt and water.

In the past, systems have found optimal operating points that balance the pressure and the volume of the feedwater. That is, low recovery means low salt concentration in the feed water and therefore low pressure because osmotic pressure is proportional to concentration. However, low recovery also means processing higher volumes of feedwater (albeit at a lower pressure). This limitation is represented by parabolic cost curves when plotting energy requirements against the rate of recovery. Optimum operating points often reflect the recovery rates at the minimums of these cost curves.

The figure below shows a series of such cost curves. The uppermost cost curve shows the case for simple reverse osmosis (RO). In this case one can see that raising or lowering the recovery rate increases the energy cost of the process from the minimum at about 60% recovery. A process that can lower the recovery and therefore the pressure required, must, by definition, pump more volume at the lower pressure. Conversely, a process designed with higher recovery can pump less volume, but must pump that volume at higher pressure given the increase in concentration. The minimum energy for such simple RO processes tends to the 50 to 65% range.

With the advent of efficient energy recovery devices, the optimal operating point started shifting to lower recoveries as can be seen on the second, lower cost curve in the figure. As energy recovery devices allowed beneficial use of the residual brine pressure, there is less waste associated with the pressurized water not converted to potable. Thus, optimal recovery rates tended lower, 30 to 40%.

Still lower energy consumption is possible by using the natural hydrostatic pressure. Researchers have successfully attempted this by submerging a spiral wound membrane system to depth in the sea. The natural pressure did the work of the pump on a traditional shore based system. However, the produced water pumped to shore had to overcome the same head of pressure used in the treatment process, seemingly eliminating the benefit. However, only the produced water must be pumped rather than the far more voluminous feed water, thus generating savings.

Past natural pressure systems were designed with membrane configurations specifically designed for traditional shore based systems. These membrane elements required water be pushed through them since they were designed for systems where water is moved with pumps. In these cases the optimal recovery rate (and energy requirement) was lower than the shore based system but were limited on the low end by the fact that these systems still required pumping the flow of the feedwater. The pumping was not for static pressure, as that existed infinitely in the sea. Rather, it was only for the movement of the feed in the volumes associated with the recovery. This limitation can be seen on the third cost curve by the steeply increasing curve at very low recovery rates.

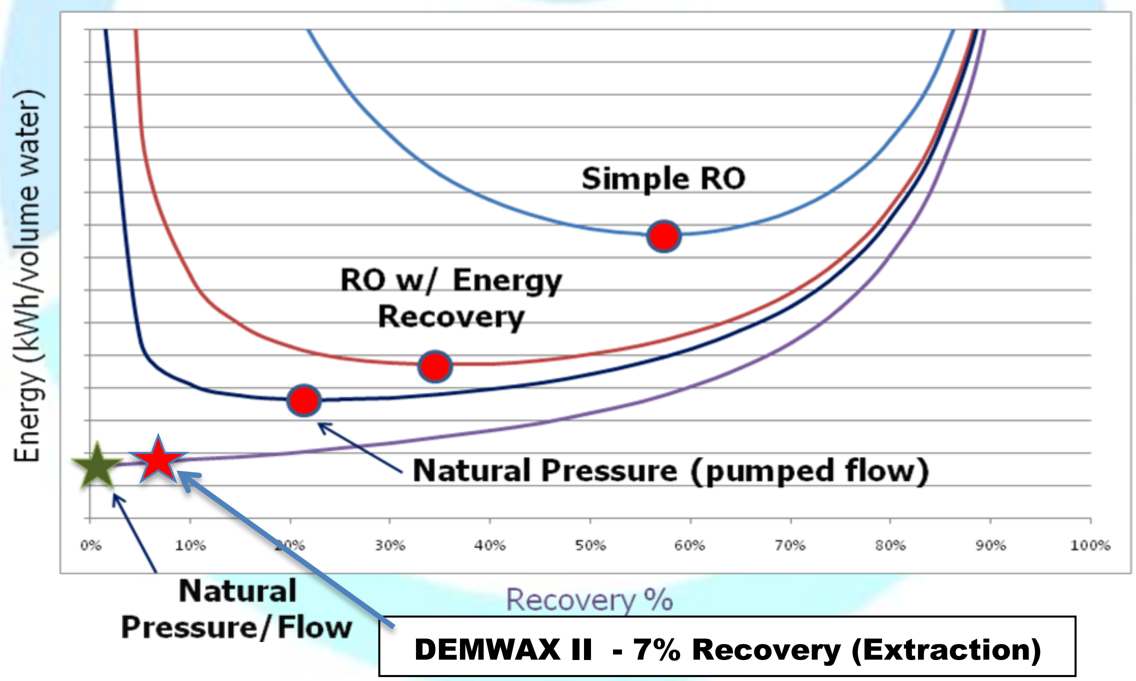



***Figure 1 - Energy vs. Recovery***

The final cost curve represents the case of the original DEMWAX™ system, using natural static pressure in the sea, but also designed to capture natural movements of the feedwater. That system used the natural forces of gravity and currents in the ocean to naturally move the feedwater. In this case, the energy requirement tends toward the physical limit at a zero recovery.

With DEMWAX II, nearly the same energy cost savings are produced onshore with a column of water inside a well bore. To do this, the inflow to the open tube containing that water column is configured several feet above the outflow from the well bore to allow gravity to move the concentrate down through the system and into the ocean. The only added energy as compared to DEMWAX then is what is required to lift the feed water the few feet to drive the movement of the feed water.

The membrane cartridge is comprised of multiple cylindrically wound reverse osmosis membranes spaced with specially designed spacers to minimize head loss. The membranes are directly exposed to the seawater in the water column. The voids between these membranes are open on the top and bottom to allow water to naturally pass through. The lower recovery rate, and thus lower pressure requirement, results in significantly reduced capital, operating and environmental costs typically associated with traditional SWRO systems. The depth needed for the DEMWAX II system in the ocean is approximately 300 meters[1].

**Energy Efficiency**

The result of the DEMWAX II design is a low energy process that harnesses natural forces efficiently. For DEMWAX II the power reduction is approximately 65% versus current state-of-the-art traditional SWRO systems. In general terms, this reduction can be summarized as half the flow at half the pressure. A typical large scale SWRO plant with energy recovery uses approximately 16 kilowatt-hours per thousand gallons of product water (or about 4.2 $kWh/m^3$). A SWRO plant that operates at 50% recovery must pre-treat and pressurize 2 gallons of feed water to yield 1 gallon of product water. At a target of about 7 percent recovery, the DEMWAX II system only needs to pump the 1 gallon of product water (besides the 16 gallons of very low-pressure inflow) or about half the flow as compared to a traditional SWRO plant.

To achieve the 50% recovery, a traditional SWRO system must reach a pressure of nearly 800 to 1,000 psi (55 to 69 bar). As osmotic pressure for typical Pacific Ocean seawater is approximately 320 to 350 psi (22 to 24 bar), the required pressure is more than twice osmotic. Since the DEMWAX II is designed to operate at extremely low recovery; the

[1] Past natural pressure systems required much greater depth in order to achieve the osmotic pressure of the more concentrated feedwater due to the higher recovery rate. See, for example: Paolo Pacetti, et al, "Submarine seawater reverse osmosis desalination system," Desalination 126 (1999) 213 – 218.

required pressure is only slightly higher than osmotic at about 350 to 400 psi (24 to 28 bar) or about half the pressure of a traditional onshore SWRO plant. This required pressure is supplied by the differential between the water column in the well bore of source water and that in the permeate collection tube.

### Water Flow and Membrane Spacing

For all membrane processes, effective transfer of source water to the membrane surface, and the removal of concentrate from the membrane surface are critical. In the spiral wound configuration, a raw water spacer is used to create a channel between the membranes to convey the source water and brine. Normally, this space is very small, on the order of 0.03 inches (0.76 mm). In a static seawater environment, even at high pressure, the feedwater and brine would not flow efficiently to match the flux and avoid excessive concentration at the membrane surface without mechanical means to remove the brine. The close spacing of the traditional spiral wound membrane would inhibit flow if no mechanical means were used.

The DEMWAX II system solves this problem. Instead of trying to force the water through a small channel, the membranes in the DEMWAX II system, by virtue of the wide specially designed spacers, have a much larger channel (increased spacing between membranes) reducing the associated friction loss. In addition, the membranes are oriented vertically to allow gravity to assist this flow. As the concentration of the seawater on the high-pressure side of the membrane increases, so does its density due to incremental increase in salinity as fresh water is extracted. Since the more dense water is slightly heavier, gravity (g) will induce a flow of the dense water from top to bottom.

*Figure 2* compares traditional SWRO tight wound membranes to the DEMWAX II open channel technology permitting less energy, less fouling and less maintenance.

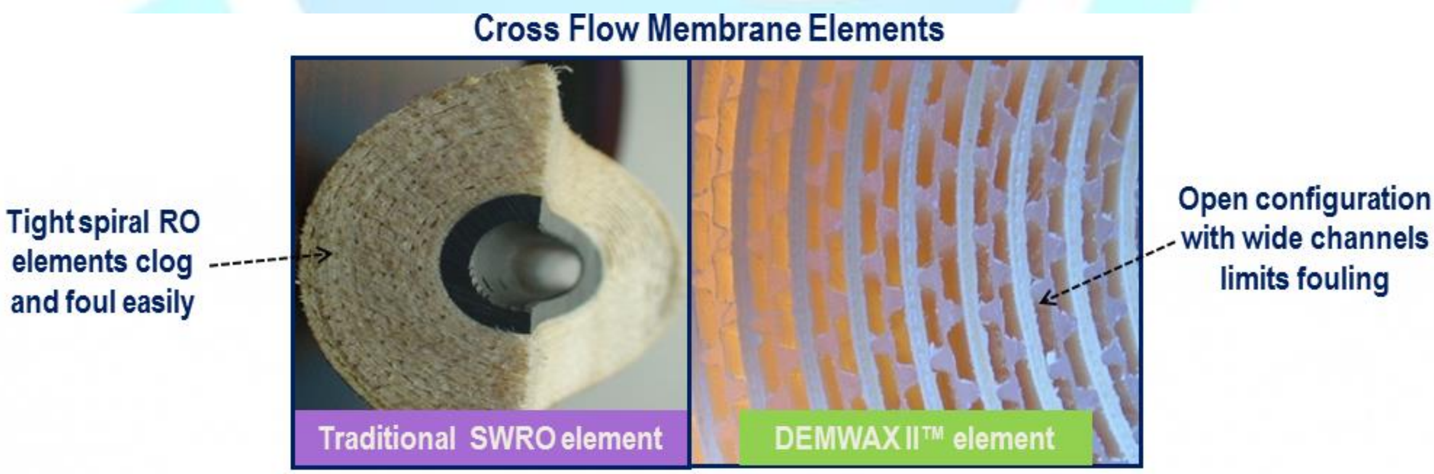



***Figure 2 - Membrane Elements***

The natural mixing effect ($m$) will pull the extra concentration of dissolved solids away from the face as is shown in *figure 3*. When some product water penetrates the membrane, the feed water right on the face of the membrane ($p$) is temporarily concentrated. As all solutions in nature seek equilibrium with regard to concentration (like a gas filling its container), the concentrated water right at the point of production ($p$) will 'jump' away from the membrane to mix ($m$) with the lower concentration water in the middle of the channel between the membranes.

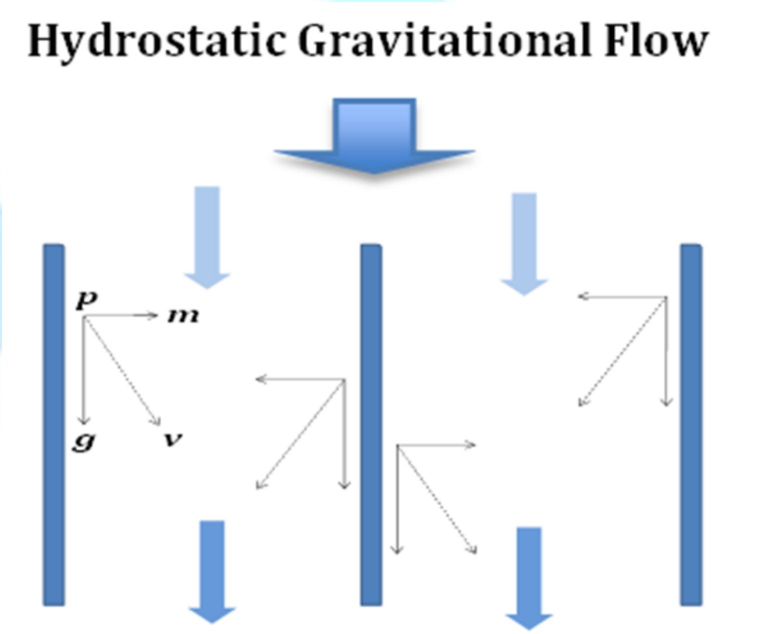



***Figure 3 - Concentration Movement in Water***

*Figure 3* shows an exaggerated cross-section of three membrane elements and the two channels they create. The DEMWAX II Membrane Cartridges are designed for this flow to occur naturally in perfectly still water, though that is never the case as inflows and outflows and gravity ($g$) generate the mixing ($m$) replenishing new feedwater when concentration briefly occurs.

This concentration movement is not as pronounced for fresh water applications. However, the concentration buildup is not as large, nor is the osmotic pressure nearly as significant.

The combination of these three effects, downward water flow, the gravity pulling down the higher density water and the mixing effect pulling toward the middle of the channel, will pull the flow in a vector ($v$) away from the membrane and down toward the floor of the well bore then back up through the outlet. As the water moves down and out of this space, more feed water will enter from the top in a constant circulation.

In conjunction with the smaller flux (30-50% of typical SWRO), the draw of water molecules out of the source water is also small in relation to the available volume between the two sheets, so the brine water is only slightly concentrated (5 to 7%) toward the bottom of the channel between the membranes.

**Pressure and Flux**

As mentioned previously, the main parameter in determining the required pressure (depth) for the DEMWAX II is the osmotic pressure of the source water. Osmosis is defined as the net movement of a solvent molecule (e.g. water) through a semi-permeable membrane from the side of lower concentration to the side of higher concentration to balance the concentrations. The osmotic pressure is the amount of pressure applied to the high concentration side of the semi-permeable membrane to prevent osmosis from occurring. In other words, the osmotic pressure creates a steady-state for two solutions where no movement occurs across the membrane. If the applied pressure is less than the osmotic pressure, natural osmosis occurs. If the applied pressure is greater than the osmotic pressure, then the flow of the solution from the high concentration to the low concentration occurs. This is reverse osmosis.

The theoretical calculation for the osmotic pressure of a solution is based on the summation of the molarity of the different molecules and the temperature of the solution. The molarity is defined as the number of molecules in the solution divided by the volume of the solution. In general, the osmotic pressure can be approximated by dividing the Total Dissolved Solids (TDS) in mg/l by 100 (e.g. 35,000 mg/l TDS = 350 psi (24 bar)).

The actual required osmotic pressure is the differential between osmotic pressure of the brine and the osmotic pressure of the permeate water.

The other pressure component that determines the required depth in addition to the osmotic pressure is the transmembrane pressure (TMP). The TMP can be thought of as the 'friction loss' across the membrane added to the driving pressure needed to produce the required flow. Just like any 'conduit,' there is a certain amount of energy required to move the water through the membrane at a certain flow rate. In order to get a particular flow through the membrane, the pressure must be greater than the combination of the osmotic pressure and the TMP at that flow. For SWRO membranes the TMP can be as high as 120 to 150 psi (8.3 to 10.3 bar) for the normal high flux operations. However, in the low flux DEMWAX II applications, it is approximately 20 to 40 psi (1.4 to 2.8 bar). For NF membranes it is even lower at approximately 10 to 20 psi (0.7 to 1.4 bar).

As the osmotic pressure is a fixed constant of the source water, technological advances in membrane construction can only improve (lower) the transmembrane pressure requirement. Since the DEMWAX II system can accommodate any membrane, such advances can be easily incorporated if warranted. However, the transmembrane pressure for seawater applications is a small fraction of the total pressure required, so the system is near the theoretical minimum energy.

The resulting total driving pressure for seawater desalination applications of the DEMWAX II system is approximately 370 to 400 psi (850 to 950 feet of depth or 255 to 285 m) based on a typical Pacific Ocean salinity. This will put the membrane cartridges at a comparable depth in the well bore.

Fresh surface water is generally low in dissolved solids (usually less than 1,000 mg/l), thus does not require significant osmotic pressure (about 10 psi). Using a mid-range (50% removal) NF membrane, the required driving pressure is on the order of 25 psi (55 feet or 16.8 m) for a medium range flux. However, well bore depths required for the myriad of different applications can span a broad range depending on source water constituents, desired treatment and flux requirements.

Many fresh water bodies, especially in mountain regions, are exceptionally clean and require filtering out larger biological contaminants only. In this case, a 'loose' nanofiltration DEMWAX II can be submerged into approximately 20 to 30 feet (9.1 m) of water in the well bore. If a water source is high in calcium carbonate, such as the lower Colorado River in the United States, a well bore depth in a reservoir of approximately 75 to 100 feet (22.9 to 30.5 m) can remove most of the calcium. However, as calcium carbonate is relatively harmless (though not to fixtures or water heaters) the DEMWAX II can merely treat the water for larger molecular contaminants at a far lesser well bore depth.

**General System Description**

The basic components are the same for either of the primary applications and include the following:

- DEMWAX II Cartridge Module – Composed of membrane cartridges, permeate tube interface, and submersible permeate pump.

- Well Bore – cased to variable depths and diameters, source water and product water dependant. It is the basic structure and connects to the outflow pipe, which is lower in elevation than the inner tube inflow pipe.

- Inner Tube – Open tube top and bottom feeding source water through inflow pipe higher in elevation than well bore outflow pipe. This provides the moving water column generating the necessary pressure differential to drive the reverse osmotic action.

- Permeate Tube – Small diameter tube inside the inner tube to transport permeate to ground level storage tank/municipal water utility.

- Electrical and control umbilical – Power for the pump and instrumentation cable to provide control of the pump and system monitoring are required.

- Ancillary systems – These systems include the power source, monitoring instruments, cleaning/fouling prevention systems, etc.

***Figure 4 - General DEMWAX II Plant Layout Comparison***

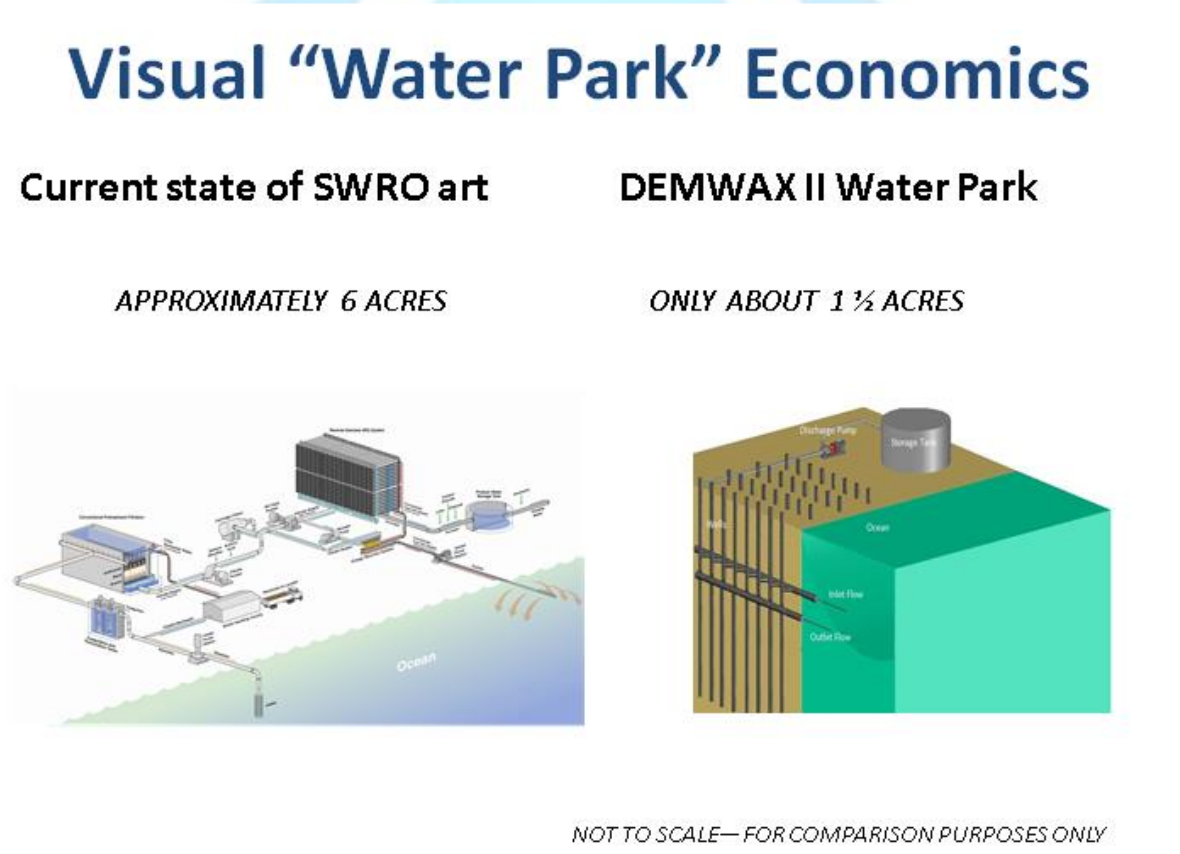



*Figure 4* provides a schematic of the general DEMWAX II plant configuration in comparison to a traditional SWRO plant graphic.

*Figure 5* shows a not-to-scale concept rendering of a DEMWAX II system. In this image, the membrane cartridge and permeate tube is the blue system inside the inner tube. The water flow in and out is illustrated in red. And the inflow/outflow differential both in elevation and direction is shown in the solid works center figure. Note that the inner tube is open at the bottom (for removal of brine) and at the top to atmospheric pressure creating the necessary pressure differential to effect the reverse osmotic process.

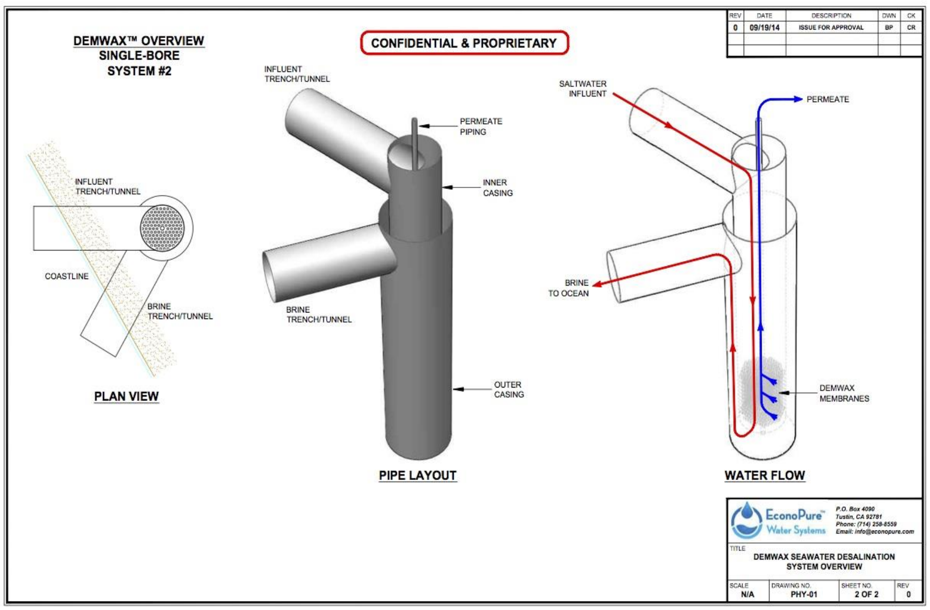
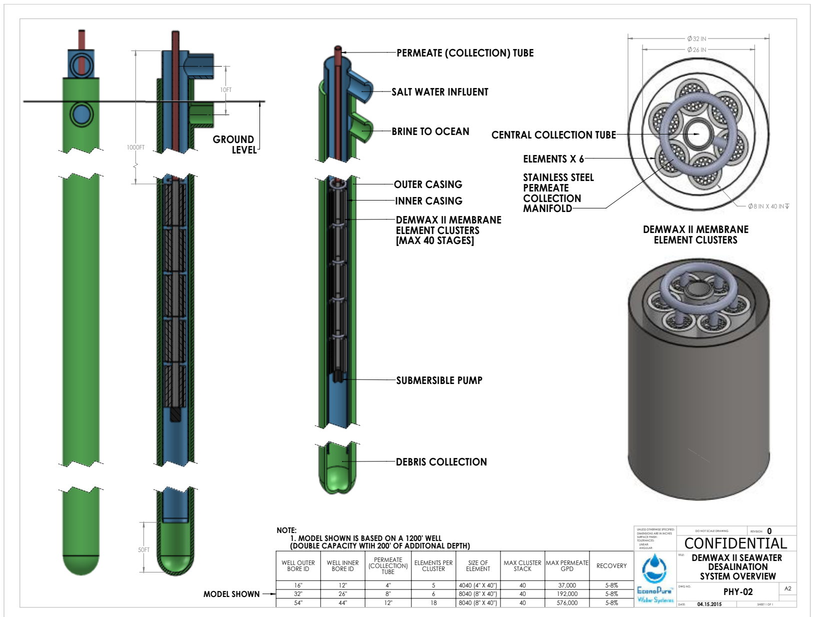



***Figure 5 – DEMWAX II System***

*Figure 6* provides some concept detail for the system; both the fresh water version and the seawater version would be the same with the exception of the depth and the distance from shore.

# DEMWAX'II'Concept'Detail'




| WELL OUTER BORE ID | WELL INNER BORE ID | PERMEATE (COLLECTION) TUBE | ELEMENTS PER CLUSTER | SIZE OF ELEMENT | MAX CLUSTER STACK | MAX PERMEATE GPD | RECOVERY |
|---|---|---|---|---|---|---|---|
| 16" | 12" | 4" | 5 | 4040 (4" X 40") | 40 | 37,000 | 5-8% |
| 32" | 26" | 8" | 6 | 8040 (8" X 40") | 40 | 192,000 | 5-8% |
| 54" | 44" | 12" | 18 | 8040 (8" X 40") | 40 | 576,000 | 5-8% |

***Figure 6 – DEMWAX II System Detail***

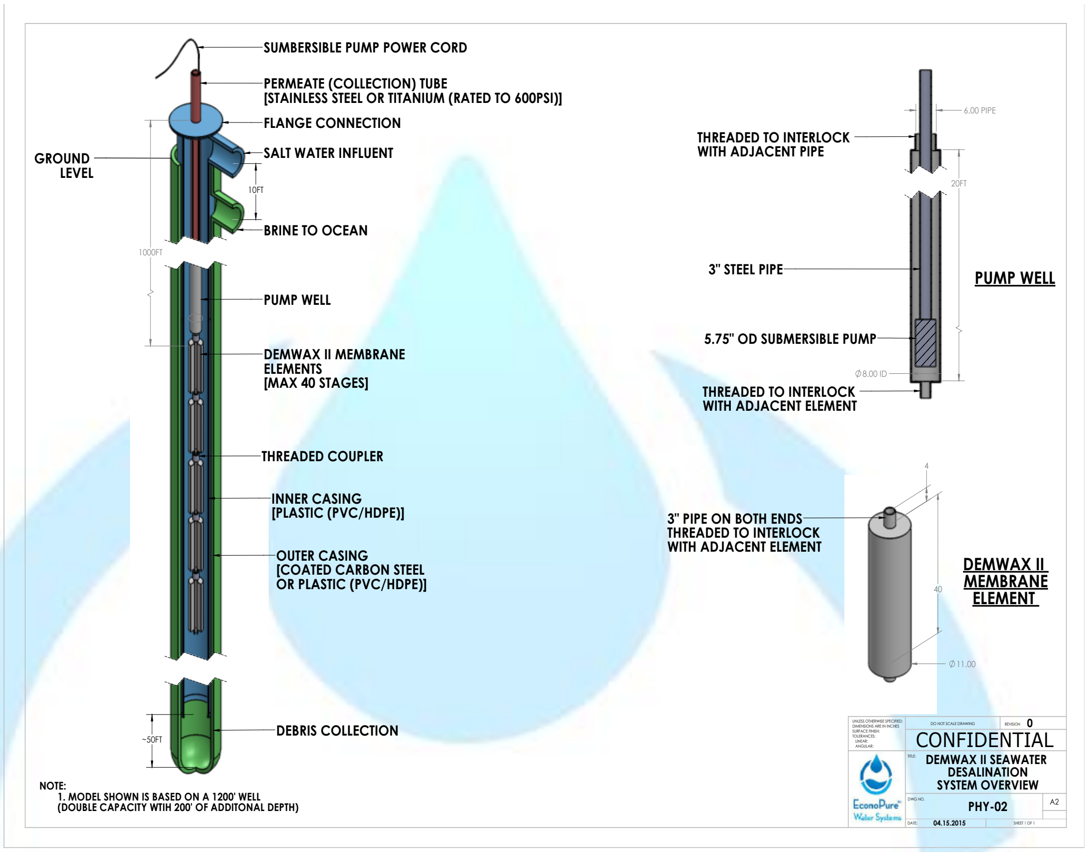
### Membrane Cartridge Cluster

The basic component to the system is the membrane cartridge cluster. A typical cluster will contain a number of spiral wound membrane cartridges (vertically arrayed) connected to the permeate collection manifold which in turn is connected to the permeate collection tube. Multiple clusters can then be stacked in quantity necessary to produce the design capacity of the system. For example, illustrated in Figure 6 there are six cartridges per cluster with a maximum stacking of 40 clusters in the 1200' deep 32" diameter well bore which will produce 192,000 gallons of permeate per day. Each cylindrical cartridge is 8" in diameter and 40" long.

### Advanced Development

With initial acceptance of the DEMWAX II technology we anticipate further technological development for major, high volume applications. One such advance will be the direct interface between the membranes and the permeate collection tube. *Figure 7* illustrates such advance.

**Value Engineering Advance**




There should be several advantages to this development, the most important of which is the increase in square foot of membrane per available inner tube volume. It will directly increase output and efficiency.

**Ancillary Developments**

As with other advances in technology we anticipate cost savings with learning curve progress and volume manufacturing of pumps, spacers, cartridges, manifolds, connections and instrumentation.

## Competitive Advantages

DEMWAX II offers many competitive advantages as compared to traditional seawater desalination and fresh surface water treatment systems. The value of the technology is derived from these competitive advantages. Many of these advantages have already been described in detail. The purpose of this section is to provide a concise summary of the concepts. The advantages are listed with a discussion of the primary applications, seawater and surface water, where warranted.

The primary competitive advantage is that DEMWAX II is dramatically less expensive than existing methods of desalinating and processing water.

***Energy Efficiency***

*Seawater or brackish water* – “Half the pressure, half the cost” is a general way to describe the DEMWAX II efficiency. In reality DEMWAX II will save more than half of the energy associated with traditional SWRO. The only generated power necessary in the inflow pump, a low-head-high-efficiency pump and the small permeate pump in the inflow tube. The main power sources are hydrostatic pressure and gravity.

***No Pre-treatment Required***

*Seawater* – Onshore plants force feedwater through extremely closely spaced membranes at high pressure and velocity. Suspended solids in the source water become abrasive projectiles that damage the membranes. Thus, traditional SWRO plants employ a costly pre-treatment process applied to all the feedwater (about twice the product water) which removes these organics and sediments. Suspended matter in the source water just flows harmlessly through the DEMWAX II membranes, making any pre-treatment unnecessary.

***Higher Quality Product Water***

*Surface water* – The nanofiltration membrane used by DEMWAX II to treat surface water removes far more contaminants than ultrafiltration or microfiltration membranes which are becoming common today. The increasing level of man-made contaminants, such as dissolved pharmaceuticals, in water sources requires that a more robust treatment process be implemented and regulations are increasingly stipulating higher water quality.

***Mitigation of ‘Brine’ Disposal***

*Seawater* – Brine disposal is an issue that must be addressed in traditional reverse osmosis plants. Because of the low-recovery process, DEMWAX II will only create ‘brine’ that is approximately 7% more concentrated than the surrounding ocean. Such low levels of concentration will mix back to ambient within a few feet of exiting the outflow channel.

***Virtual Elimination of Sea Life Impingement and Entrainment***

*Seawater* – The impingement and entrainment of sea life is another environmental hazard that haunts many power and desalination plant entitlement efforts. The velocity through the “intake” of DEMWAX II is an order of magnitude less than that in typical desalination plant intakes.

***Less Land; Economies of Factory Assembly***

Aside from the well bores, channels and attendant piping, there is little site construction necessary in a DEMWAX II water park. The element manifold and assembly can be constructed offsite and delivered turnkey. This eliminates the need for additional expensive coastal land for onsite assembly. Additionally there less expensive ocean side land used in that water park, typically 75% less than land used by a modern SWRO plant.

***No Moving Parts Subject to the Corrosive Feedwater***

Traditional desalination plants incur significant capital and maintenance costs due to the handling of highly corrosive salt water and doubly concentrated brine. DEMWAX II only exposes the outside of the polyamide (plastic) membranes to the feedwater, thus eliminating the corrosion potential on the pumps. Similarly, all surfaces exposed to the salt water will either be composed of non-corrosive materials or coated with such materials.

***Economic Restoration of Natural Surface Waters with DEMWAX II "Distributed Desalination"***

The DEMWAX II system is highly scalable allowing for smaller more efficient costal water parks closer to population centers. Contrast that with the fact that there are surface water conveyance systems in the world that require far more power than the DEMWAX™ requires to produce water from the sea. As an example, the California State Water Project conveys *untreated* water from the Sacramento River Delta to Southern California at an energy cost of approximately 2.5 kilowatt hours per cubic meter. Similarly, the Colorado River Aqueduct requires approximately 1.6 kilowatt hours per cubic meter to convey *untreated* water to the coastal populations of Southern California. DEMWAX II will require about 1.4 kilowatt hours per cubic meter to produce *potable water* on shore which will not require further treatment as these other sources will (extra energy and chemicals). In addition to the energy efficiency proposition, there is an environmental value to restoring native waterways or utilizing those waters for inland purposes.

***Significantly reduced carbon footprint***

With a dramatically reduced generated power requirement comes a corresponding reduction in $CO_2$ emissions, making DEMWAX II truly a 'green' technology.

***Conclusion***

The quest for energy efficient and environmentally benign methods of extracting potable water from seawater has witnessed a series of incremental advances over the past two decades. Many experts in the field believe we are at the end of the road for improving the efficiency of seawater desalination. However, the new paradigm represented by DEMWAX II will dramatically improve efficiency while testing the physical limits of efficiency. It will do this while also improving the environmental profile by mitigating brine disposal and sea life impingement/entrainment issues.

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