# Design of Drinking Water Production System using Ground Water as a Water Source

## Environmental Engineering Project ENV 05

## Introduction

The Nong Song Hong area faces challenges with saline groundwater. In 2013, a reverse osmosis (RO) system was installed with Department of Groundwater Resources funding. However, membrane fouling led to unsustainable operational costs and system shutdown, forcing the school to rely on bottled water.

The existing pre-treatment system, consisting of granular filtration and polypropylene cartridge filters, only removes suspended solids. This limited filtration fails to prevent membrane fouling–where contaminants accumulate on the membrane surface and pores–resulting in frequent cleaning and costly replacements. To address these issues, a new pre-treatment unit is designed to reduce membrane fouling, extend membrane lifespan, and minimize operational costs.

## Objectives

1. To re-design and improve the existing RO drinking water production system at Ban Khok Sung Witthaya School, using brackish groundwater as the raw water source.
2. To estimate the installation and operation costs of the RO system to determine the return on investment (ROI) for drinking water production.

## Ground water characteristics

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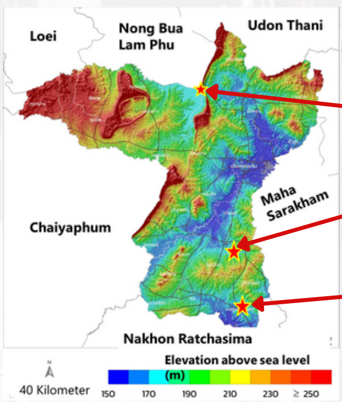
| Parameter | Unit | Groundwater | Recommended for a water source for drinking water |
|---|---|---|---|
| Physical attributes | Pt-Co | colorless | 15 |
| Turbidity | NTU | 1.94 | < 5 |
| Total suspended solids (TSS) | mg/L | < 10 | - |
| Total dissolved solids (TDS) | mg/L | 2,172 | < 500 |
| pH | - | 6.58 | 6.5 - 8.5 |
| Total hardness | mg/L as $CaCO_3$ | 530 | < 100 |
| Alkalinity | mg/L | 269 | 20 - 500 |
| Conductivity | µS/cm | 2,980 | 200–800 |
| Chloride | mg/L | 702 | ≤ 250 |
| Total organic carbon (TOC) | µg/L | 312.7±0.73% | 2,000–4,000 |
| Iron | mg/L | < 0.05 | ≤ 0.3 |




### The geography of Khon Kaen Province

**Ubolratana District**
**•TDS 170.40 mg/L**

**Ban Phai District**
**•TDS 2,000 mg/L**

**Nong Song Hong District**
**•Ban Khok Sung Witthaya School**
**•TDS 2,172 mg/L**

- The Total Dissolved Solids (TDS) in groundwater varies significantly by region Northern areas: Lower TDS concentrations. Southern areas: Elevated TDS levels, attributed to dissolved minerals and rock salt deposits

## Design criteria & Specification

**Granular filtration** removes suspended solids in the water.

- Anthracite is selected as filer media.

| Filtration Media Type | Filtration Rate ($m^3/m^2$ hr) | Design Value ($m^3/m^2$ hr) |
|---|---|---|
| Anthracite | 4.9-12.2 | 8.3 |

| Media Type | ES (mm) | UC | Layer Thickness (mm) | Specific Gravity |
|---|---|---|---|---|
| Anthracite | 0.7-1.7 | 1.75 | 450-750 | 1.4 |

**Granular activated carbon** removes color, odor, and taste

- GAC can remove organic matter and prevent organic fouling for RO membrane.

| Physical Properties of Activated Carbon (GAC) | Unit | Values |
|---|---|---|
| True Density (No Internal Void) | $g/cm^3$ | 2.0 - 2.1 |
| Bulk Density (Dry, with Internal Void) | $g/cm^3$ | 0.4 - 0.5 |
| Pore Volume | $cm^3/g$ | 0.8 - 1.20 |
| Internal Surface Area | $m^2/g$ | 600 - 1,600 |
| Effective Size (ES) | mm | 0.5 - 1.3 |
| Uniformity Coefficient | mm | 1.4 - 2.4 |

| Activated Carbon Filter Design | Unit | Values |
|---|---|---|
| Filtration Rate | $m^3/m^2$•hr | 2.4 - 14.4 |
| Filtration Rate for Color, Odor,and Taste Removal | $m^3/m^2$•hr | 9.6 - 14.4 |
| Contact Time | min | 8.0 - 30.0 |
| Minimum Filter Layer Thickness | m | 0.6 |

**Ion exchange resin** removes cations (Ca2+ and Mg2+) by exchanging them with Na+, preventing membrane fouling from scale buildup.

| Specification | Reference Values |
|---|---|
| Flow rate through the ion exchange layer | 40 $m^3$/ 1 $m^3$ of ion |
| Surface Loading Rate | - Long-term: 15 $m^3$/ $m^2$ hr.<br>- Short-term: 20 $m^3$/ $m^2$ hr. |
| Ion Exchange layer expansion during backwash | 50-75% |
| Brine flow rate during regeneration | Should not exceed 7 $m^3$/ hr. per 1 $m^3$ of Ion Exchange |
| Depth of the ion exchange layer | > 0.6 m |

**Cartridge filter** removes particles to prevent particle fouling.

| Type | Micron Rating | Cartridge Length |
|---|---|---|
| HF.Zs | 05 = 5 µm | 101.6 cm |

**RO membrane** is designed to remove NaCl from brackish groundwater.

| Model | Average Permeate Flow ($m^3$/day) | Average NaCl Rejection | Minimum NaCl Rejection | Membrane Area ($m^2$) | Outer Wrap |
|---|---|---|---|---|---|
| AG4040FM | 9.1 | 99.50% | 99.00% | 7.9 | Fiberglass |

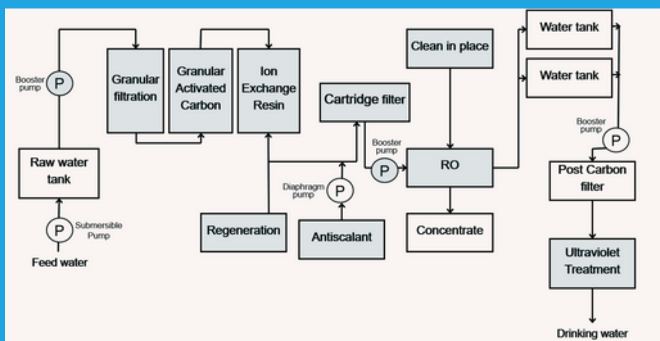
**UV sterilization system** deactivates virus and bacteria to produce safe drinking water.

| Specification | Details |
|---|---|
| Model | UVF-15W |
| Flow rate | 8 LPM (0.5 $m^3$/Hrs) |
| Voltage (Power/Lamp) | 20W/15W |
| Power Supply | 220 VAC |
| LxWxH (cm) | 55 x 15.5 x 16.5 |
| Inlet / Outlet | Male 3/4" |
| Operating Pressure (Bar) | 4.2 Max |
| Temp (°C) | 2-40 |
| Body Material | Stainless Steel 304 |
| UV Lamp Type | 2 pin double-ended |
| Certificate | CE |

| Item | Unit | Low Pressure Low Intensity | Low Pressure High Intensity | Medium Pressure |
|---|---|---|---|---|
| Germicidal output/input | % | 30–40 | 25–35 | 10–15 |

| Type of Water | $UV_{254}$ Absorbance, (AU/cm) | Transmittance $UV_{254}$, (%) |
|---|---|---|
| Surface water after reverse osmosis | 0.0458–0.0044 | 90–99 |

## Design for the new RO drinking water system



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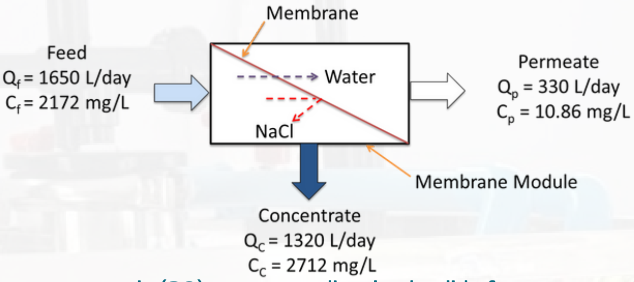
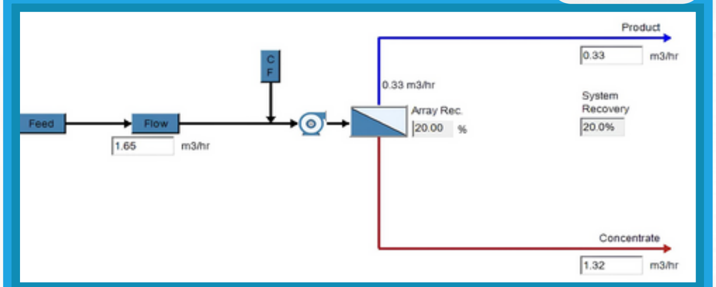
## Design and calculation results




- Reverse osmosis (RO) separates dissolved solids from water using a semi-permeable membrane.
- The permeate (filtered water) has low concentration of dissolved solids, achieving up to 99.5% rejection of NaCl.
- Dissolved solids that cannot pass through the membrane are retained in the concentrate stream.

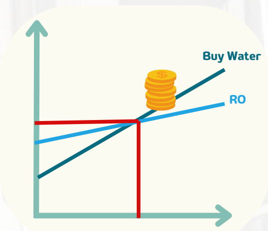
### RO system design using winflows software




| System Data | | Single Pass Design |
|---|---|---|
| Temperature: C | RO-1:25.00 | |
| | | RO 1 |
| Feed Flow to 1st Stage Housing | m³/hr | 1.65 |
| Feed Pressure | psi | 205.75 |
| Array Recovery | % | 20.00 |
| Permeate Flow | m³/hr | 0.33 |
| Split Permeate Flow | m³/hr | 0.00 |
| Pump Summary | | |
| Main Pump | | RO 1 |
| Feed Flow | m³/hr | 1.65 |
| Inlet Pressure | psi | 0.00 |
| Discharge Pressure | psi | 205.75 |
| Total Efficiency | % | 82.88 |
| Power | kW | 0.78 |
| Total Power Consumption | kW | 0.78 |

| Parameter | Feed | Product | Concentrate |
|---|---|---|---|
| Alkalinity, PPM CaCO3 | 120 | 0.8 | 149.79 |
| TDS, mg/l | 2476.33 | 17.74 | 3091.01 |
| pH | 6.58 | 4.8 | 6.66 |
| LSI | -4.59 | -10.33 | -4.35 |
| Stiff Davis | -4.79 | 0 | -4.53 |

## Estimation cost



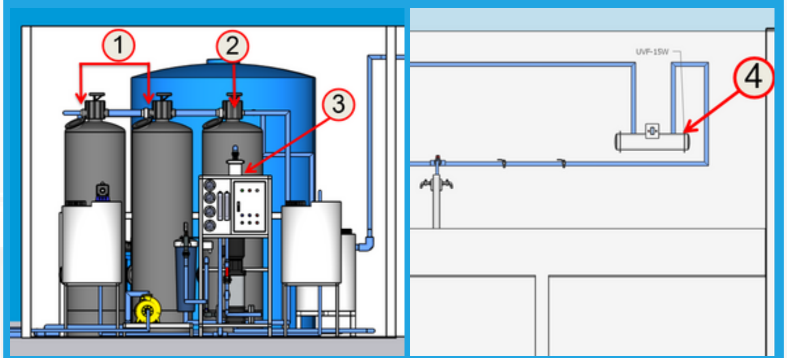

Purchasing Drinking Water

- No installation cost
- Water purchase cost = 83,300 THB/year

RO System

- Initial capital investment = 283,048.79 THB
- Operation cost = 38,412.72 THB/year
- Payback Period = 6.31 years

## Equations for the design




### 1. Anthracite and GAC filters

**Reynold number**

$$R = \frac{\Phi d V_a}{\mu}$$

**Drag coefficient**

$$C_d = \frac{24}{R} + \frac{3}{\sqrt{R}} + 0.34$$

**Head loss through media and Underdrain**

$$h_L = \frac{1.067 V_a^2 D}{\Phi g \varepsilon^4} x \frac{C_D f}{d}$$

**Porosity of expanded bed**

$$\varepsilon_e = \left(\frac{V_b}{V_s}\right)^{0.22}$$

**Settling velocity**

$$V_s = \sqrt{\frac{4}{3}\frac{g}{C_d}(SG-1)d}$$

### 2. Ion exchange resin

**The amount of resin**

$$Equivalent\ (gm-eq) = \frac{g}{Eq-Wt}$$

$$Equivalent\ weight = \frac{Molecular\ Weight(M.W.)}{2}$$

**Water hardness**

$$Hardness\ in\ \frac{mg}{l}\ as\ CaCO_3 = \frac{M^{2+} in\ mg/l \times 50}{Equivalent\ weight\ of\ M^{2+}}$$

### 3. RO system

**Water flux :**

$J_w = k_w (\Delta P - \Delta\pi) = Q_P/A$

**Pressure drop :**

$Pressure\ drop = P_f - P_p$

**Recovery :**

$r = Q_p / Q_f * 100$

**Flow balance :**

$Q_f = Q_p + Q_c$

**Rejection :**

$R = (C_f - C_p) / C_f * 100$

**Mass balance :**

$Q_f C_f = Q_p C_p + Q_c C_c$

**Transmembrane pressure :**

$P_{tm} = (P_f + P_c)/2 - P_p$

**Osmotic pressure :**

$\Delta\pi = (C / M)*RT$

### 4.UV sterilization system

**Reactor Volume**

$$V = \frac{\pi(D-d)^2 h}{4}$$

**Surface area of UV lamp**

$$A = 2\pi r h$$

**Absorption coefficient**

$$\propto = 2.303 k_A(\lambda)$$

**Average UV Intensity**

$$I_{avg} = I_0 \frac{(1-e^{-\propto d})}{\propto d}$$

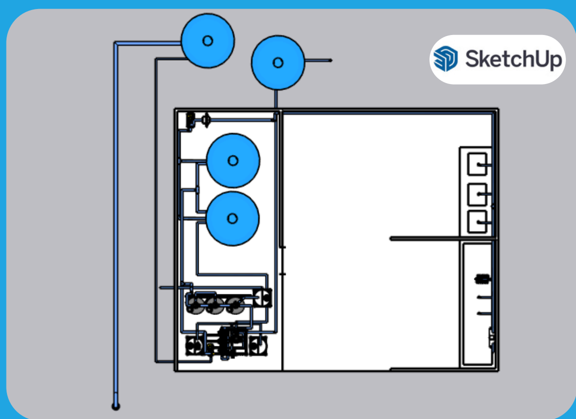
**Hydraulic Contact Time**

$$t = \frac{V_{reactor}}{Q}$$

**UV Dose**

$$UV\ Dose = I_{avg} \cdot t \cdot \frac{\Theta}{t} \cdot F_h \cdot F_p \cdot F_t$$

## Top view projection of the RO system




## Results

The project focused on designing and enhancing a Reverse Osmosis (RO) water treatment system at Ban Khok Sung Wittaya School, using brackish groundwater as the raw water source. The RO system includes a granular filter, activated carbon, ion exchange, and a cartridge filter as pre-treatment stages. To ensure safe, high-quality drinking water, a UV system is installed after the RO process.

A cost analysis found that while the initial installation cost was higher than purchasing drinking water, the system could break even within 6.31 years. The annual operating costs, operating costs, including maintenance, were lower than the cost of buying bottled water. This makes the project a cost-effective and sustainable solution, significantly reducing the school's water expenses.


**Reference :** Srisuk (2008) , KetsudaSriburin, (n.d.) , Mitrearth, (n.d.); Ministry of Public Health (2022) ;Paisarn Veerakit (2012); Veolia Water Technologies & Solutions (n.d.); John C. Crittenden, R. Rhodes Trussell, David W. Hand, Kerry J. Howe and George Tchobanoglous (2012); Suez (n.d.)



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