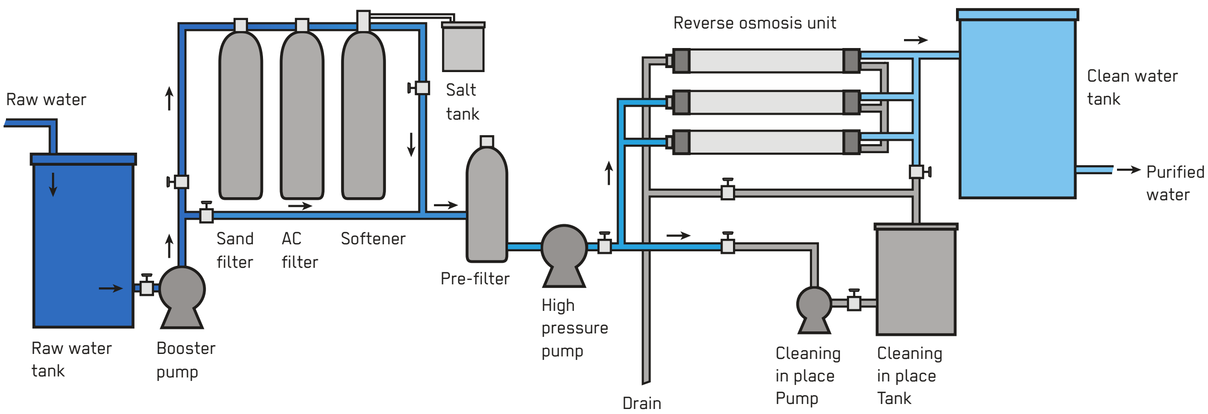
Nanofiltration (NF)/Reverse Osmosis (RO)

Response Phase	Application Level	Management Level	Objectives / Key Features
** Acute Response ** Stabilisation ** Recovery	* Household ** Neighbourhood ** City	* Household ** Shared ** Public	Removal of dissolved organic and inorganic contaminants
Local Availability	**Technical Complexity**	**Maturity Level**	
* Low	*** High	*** High	



Nanofiltration and Reverse Osmosis (NF/RO) have essentially the same equipment arrangements, and both remove contaminants by applying pressure to water across a semi-permeable membrane. RO is used to desalinate brackish water and seawater and removes organic and inorganic compounds (e.g. nitrate) and microorganisms. The key difference is that NF removes less salt (e.g. NaCl) and other monovalent ions than RO and is mainly used to remove colour, organic contaminants (e.g. pesticides) and lower the hardness (softening). Distillation, such as a solar still made of local materials, is a potential alternative. A related method, membrane distillation, is typically not commercially available.

Generally, NF/RO units are prefabricated. Some large systems are constructed on-site. RO/NF needs a reliable, uninterrupted, pressurised water supply, disposal locations for the concentrate (continuously generated) and cleaning wastes (intermittently generated), a reliable source of electricity, cartridge filters, specific chemicals for anti-scalant and cleaning, and typically pre- and post-treatment. Energy consumption is higher than for other treatment technologies except distillation. RO systems remove a wide range of contaminants, and element data sheets indicate new, single-element salt rejections above 99 % with full-scale performance typically providing over 95 % removal. NF generally removes > 95 % of organics (e.g. pesticides) and reduces hardness by about 50–80 % and NaCl by about 20–40 % (NF rejection is more site-specific than RO). RO water usually has a low pH that is unstable and corrosive. Re-mineralisation of the treated water might be required.

Design Considerations: Design considerations include pre- and post-treatment, waste disposal, membrane type and the presence of a reliable electrical supply. For low turbidity (< 0.3 NTU) water, minimal pre-treatment (5-micron cartridge filtration and anti-scalant addition) may be sufficient. Otherwise, additional pre-treatment is advised, such as Ultrafiltration **(T.10)** or granular media filters and support equipment. A silt density index of < 5 is required by warranties (< 4 is desired). Chlorine will damage the membrane so should be removed prior to RO filtration. Post-treatment usually includes adding

chemicals for disinfection and to prevent the downstream corrosion of piping and fixtures, such as by increasing the pH (via controlled addition of potable quality caustic, sodium hydroxide). Periodic cleaning in place (CIP) can recover the membrane permeability, which reduces over time due to scaling and fouling. Careful waste disposal is needed as the concentrate and spent cleaning solutions contain high concentrations of pollutants.
NF/RO parameters include feed water flowrate and pressure, flux (rate water passes through area of membrane) and recovery (ratio of permeate to feed flow). Feed pressure (and related electrical use) varies with feed water quality, salt content, temperature and membrane type. While difficult to generalise, the feed pressure for seawater is about 65 bar and, for water with lower salt concentrations, can be as low as 7–15 bar. Excessive flux results in a short service life, capacity shortfall and higher operating costs. Pilot testing can confirm stable flux, which is typically about 15–25 L/m^2/hour. NF/RO filters are operated in cross-flow mode and part of the feed is recirculated. Overall, about 50 % of a seawater feed becomes permeate, and with lower salt concentrations, the typical recovery is 70–85 %. A detailed evaluation of water quality is needed to properly design NF/RO. Manufacturers often provide software to aid calculations.

Materials: Membrane elements and vessels are made of special plastics. Low pressure piping (up to about 3.5 bar) may be non-metallic (e.g. fiberglass/plastics or stainless steel). Materials subject to corrosion (e.g. carbon steel, galvanised, ductile iron, copper, etc) are not used. Some materials may need to be imported.

Applicability: NF/RO can be used in the acute response and possibly the subsequent stabilisation and recovery phases. It can be used as a one step-treatment, as it has excellent filtration quality. Automated small-scale, skid-mounted systems are available that can be set up in a few hours and are sometimes applied in remote locations. In situations when only saline or brackish water is available or groundwater wells are contaminated with salt water (e.g. due to a tsunami), RO systems might be the only way of quickly desalinating water. Due to the high complexity, energy demand and costs particularly for longer-term operation, other technologies might be considered first, especially when the contaminants are primarily pathogenic microorganisms.

Operation and Maintenance: Key operational costs include electricity, chemicals, cartridge or membrane filters, operator and caretaker costs, and long-term replacement of the RO elements. It is imperative that the staff operating RO/NF are well trained and are supported on a long-term basis. As O & M procedures require experience with the respective system design as well as process automation, electronics and online monitoring, qualified personnel should maintain RO/NF for long-term viability. Thus, good after-sales and on-site support should be available locally through a distributor or manufacturer. To minimise membrane fouling and scaling, anti-scaling agents and other chemicals are frequently used. The membrane service life may reach up to 5 years before replacement.

Health and Safety: The removal of viruses, bacteria, Giardia and Cryptosporidium ranges from about 2-log (99 %) to 4-log (99.99 %) and higher. The operation of RO requires potentially dangerous chemicals, such as acids and bases. Proper transportation, storage and training are needed to ensure operator and public safety. The most common hazards are found in working at height, exposure to noise and chemicals, contact with rotating equipment, electricity, high-pressure fluids and fire. Waste (concentrate and spent cleaners) needs to be disposed of in a safe, environmentally acceptable way, as it contains concentrated contaminants.

Costs: Overall, RO/NF is a high-cost technology. Mobile RO plants with a capacity of 1,000–2,000 L/h cost from 10,000–100,000 USD depending on the manufacturer and configuration. Transportation costs could be high depending on location. Operational costs are also high due the requirements for power, special chemicals, cartridge filter replacement and skilled operators.

Social and Environmental Considerations: Due the complexity of the equipment and operations, specialised, educated, well-trained operators are needed, which may not be available on location. Water tastes flat, which can lead to user rejection. NF and RO produce brine (concentrated salt solution) as a waste product, which is harmful to aquatic environments. Both systems have high energy consumption. When fossil fuels are used for power, there is a high CO_2 footprint.

Strengths and Weaknesses:

(+) RO technology is very effective in removing many types of contaminants, including salt
(+) Proven technology, simple monitoring of water quality through basic parameters, such as conductivity
(+) Is prefabricated and easily transportable in smaller sizes, with mobile modular systems available

(−) Has high initial purchase and operating costs
(−) Requires reliable power; power use is higher than conventional water treatment
(−) Requires detailed design based on raw water chemistry and site-specific issues
(−) Requires well-trained operators, high-quality materials and equipment, and expensive/imported and/or dangerous chemicals

→ **References and further reading material for this technology can be found on page 219**