Water Dialogues

Artificial recharge of aquifers

Type: Mitigation
Driver: Excess groundwater extraction
Where: Across the land surface
Function: Store surplus surface water and restore pressure in the aquiver

Description of the measure:
The main purpose of artificial aquifer recharge is to store excess water by recharging the aquiver (Dos Anjos, 1998). Artificial recharge can be done through injection of water through wells. This method often is applied to recharge deep aquifers where the natural groundwater is not effective at recharging these aquifers. This can prevent the drawdown of the water table and the land subsidence. There are some considerations in designing the pumping and artificial recharge strategy to control land subsidence by preventing the shift of deformation feature, such as continued subsidence after pumping has ceased, appropriate time scale, and locations of key monitoring points (Wilson and Gorelick, 1996). It is important to consider these strategies, since artificial recharge may have little effect on the land subsidence when the groundwater level in the cone of depression is lower than its previous still water level (Shi, 2016). Artificial aquiver recharge can be used to harvest floodwaters and simultaneously reduce flood risk (He et al., 2021).

- **Short-term effects**

In the short-term, the artificial recharge can minimize the rainfall run-off over the surface area. Henceforth, it will reduce the risk of flooding. It also helps to supply water resources in urban areas.

- **Long-term effects**

The artificial recharge helps to rise the groundwater level and play an important role to affect the deformation process. The artificial recharge also helps to stimulate land rebound (Zhang, 2015), normally small or insignificant (Bouwer, 1977). As a consequence, this will prevent the land subsidence.

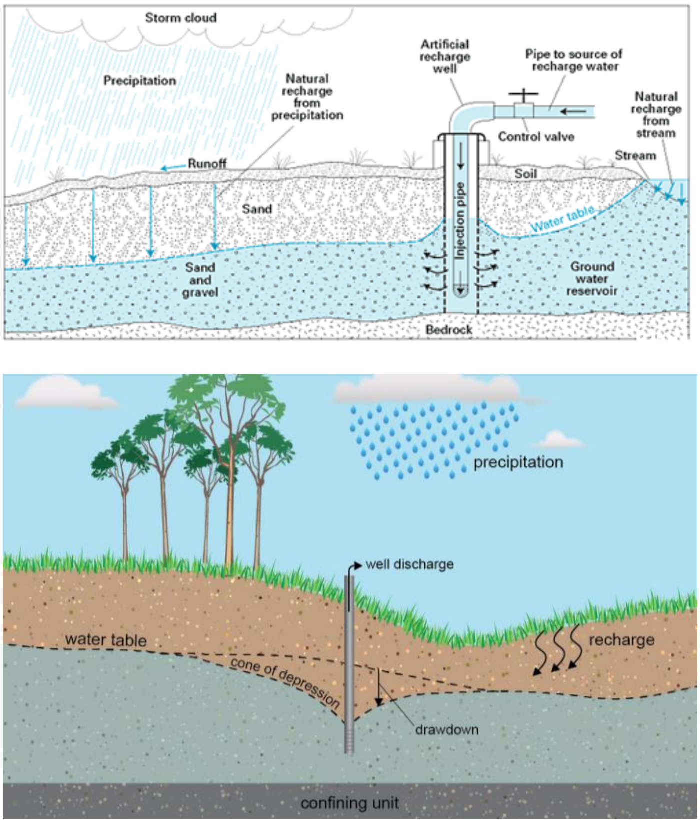

Figure 1 Artificial recharge of aquifers (USGS)

Operation and maintenance requirements
Maintenance is labor-intensive and generally involves regular silt removal. Repairs to the guard walls, covers, and iron grilles are also needed.

Examples

- Artificial recharge implementation through injection wells in Shanghai (Shi, 2016)
- Barbados deep injection wells: (https://www.nationnews.com/2018/03/09/bwa-working-on-second-injection-well/)

Co Benefit

- *Controls saltwater intrusion into coastal aquifers*
- *Reduces the risk of flooding*

Disadvantages

- *Potential for contamination of the groundwater from injected surface water runoff*
-

Implementation Cost ($-$$$)	Maintenance costs	is it green
$$$	$$$	no

Bouwer H., 1977. Land subsidence and cracking due to groundwater depletion. Ground Water 15(5): 358–364

Dos Anjos, N.D.F.R., 1998. Source book of alternative technologies for freshwater augmentation in Latin America and the Caribbean. *International Journal of Water Resources Development*, *14*(3), pp.365-398.

Shi, X., Jiang, S., Xu, H., Jiang, F., He, Z. and Wu, J., 2016. The effects of artificial recharge of groundwater on controlling land subsidence and its influence on groundwater quality and aquifer energy storage in Shanghai, China. *Environmental Earth Sciences*, *75*(3), p.195.

Zhang, Y., Wu, J., Xue, Y., Wang, Z., Yao, Y., Yan, X. and Wang, H., 2015. Land subsidence and uplift due to long-term groundwater extraction and artificial recharge in Shanghai, China. *Hydrogeology Journal*, *23*(8), pp.1851-1866.

He, X., Bryant, B.P., Moran, T., Mach, K.J., Wei, Z. and Freyberg, D.L., 2021. Climate-informed hydrologic modeling and policy typology to guide managed aquifer recharge. *Science Advances*, *7*(17).

Wilson, A.M. and Gorelick, S., 1996. The effects of pulsed pumping on land subsidence in the Santa Clara Valley, California. *Journal of hydrology*, *174*(3-4), pp.375-396.

Water Conveyance by Pipelines (Improve water supply coverage)

Type: Mitigation
Driver: Alternate water source
Where: Distributed
Function: Centralized distribution of water to urban areas

Description of the measure:
Water from various rivers or a reservoir is pooled to a water treatment plant (WTP). Inside the plant, the water is processed through various steps, such as coagulation, flocculation, sedimentation, filtration, and disinfection. Afterwards, the water is channeled to urban areas through pipelines. This measure helps to substitute the groundwater extraction in clusters of household.

- **Short-term effects**

The pipeline can effectively convey water to the urban areas short-term. Distributed water is transported without degradation in quality or evaporative losses. Natural variations in the water supply will be reduced causing better accessibility to water during the dry season.

- **Long-term effects**

Long-term, the pipeline will reduce the groundwater extraction in the area. This helps to prevent drawdown of water table resulting in a decrease in the land subsidence rate.

Operation and maintenance requirements
Medium to high skill is needed to operate the systems. It also involves some technical training for the operators. The pipelines need regular maintenance such as: repairing the pumps, pipes, and canals, and periodic upgrading of the facilities. Problems with water leaks, pumps, and storage facilities require prompt action in order to prevent interruption of services.

Figure 2 Pipelines (Canusa-CPS)

Examples
Piped water supply is common around the world. Private and/or public water companies distribute (drinking) water. Many examples can be found in Europe and North America, some are listed below:

- Underground water pipes in United States
- Water supply in Canada

Co Benefit	***Disadvantages***
• *Improves the agricultural production*	• *The capital cost is high*

Implementation Cost ($-$$$)	Maintenance costs	is it green
$$$	$$$	no

Wastewater treatment plant (WWTP)

Type: Mitigation
Driver: Alternative water sources
Where: Mostly urban areas
Function: Reuse of wastewater (water reclamation) for various functions reducing raw water use

Description of the measure:
Wastewater can be simply defined as used water in various sectors, such as households, businesses, and industries. For example, in households, this includes water from showers, toilets, washing machines, and dishwashers. This type of water can be reused for certain uses through water treatment. The wastewater is pooled into a Wastewater Treatment Plant (WWTP) and processed through various steps. The reclaimed water can be used for urban, agriculture, industrial, recreational, or environmental purposes. The potability of the water depends on the treatment process. This measure works well together with an effective means of water distribution such as a piped water supply.

- **Short-term effects**
  Many sectors can use the reclaimed water for various purposes. Large quantities of water can be transported without degradation in quality or evaporative losses. Natural variations in the water supply will be reduced causing better accessibility to water during the dry season.

- **Long-term effects**
  By using the wastewater treatment, the groundwater usage can be minimized and the wastewater can be used effectively. Wastewater treatment helps to achieve Zero Liquid Discharge (ZLD) in the area. Consequently, the lowered waste volumes will decrease the cost associated with waste management. It will reduce the groundwater extraction and as the result, prevent the land subsidence.

Figure 3 The Central Wastewater Treatment Plant in Nashville (USGS)

Operation and maintenance requirements

Operating the facility requires a medium to high level of technical expertise. This requires trained technicians and engineers. There are two types of maintenance for the wastewater treatment plan: corrective and preventive maintenance. The corrective maintenance is carried out when components fail or stop working. The preventive maintenance is a regular activities to prevent a breakdown. Similar to the operating requirements, the maintenance of the wastewater treatment plant also need a medium to high technical skill technician and engineer. (USEPA, 1973)

Examples

- Largest wastewater treatment plants in the world, Jean-R.-Marcotte Wastewater Treatment Plant in Montreal, Canada
- The Central Wastewater Treatment Plant in Nashville in United States

Co Benefit	Disadvantages
• *Tighter water quality control improving sanitation and hygiene*	• *The capital cost is high and large energy consumption*

Implementation Cost ($-$$$)	Maintenance costs	is it green
$$$	$$$	no

USEPA, 1973. Maintenance Management Systems for Municipal Wastewater Facilities.

Desalination plant

Type: Mitigation
Driver: Alternative water sources
Where: Nearby the coastal area
Function: Convert salt/brackish water to fresh water

Description of the measure:
Desalination is a process to remove the minerals and salts from saline water. Saltwater is desalinated to produce safe-to-use water for urban, agricultural, and even potable uses. By this technology, "unlimited" seawater is usable for various purposes. There are some methods to desalinate saline water, such as solar distillation, Multi-Stage Flash Distillation (MSF), Multi-Effect Distillation (MED), Reverse Osmosis (RO), and ionic exchange. These methods usually use thermal, mechanic, electrical or chemical energy as its primary energy source. (Kabeel, 2013). Generally, desalinating saline water is more costly and consumes a large amount of energy,

- **Short-term effects**

Urban and agricultural developments can utilize desalinated water for various uses, including drinking water. Since the distribution of water uses the pipelines, large quantities of water can be transported without degradation in quality or evaporative losses.

- **Long-term effects**

The desalinated water can substitute the groundwater. This will help to reduce the extraction of groundwater and consequently, slow down the land subsidence rate. However, the widespread desalinization may take a heavy toll on ocean biodiversity; as such facilities' intake pipes essentially vacuum up and inadvertently kill millions of microbial organisms that constitute the base layer of the marine food chain (https://www.scientificamerican.com/article/the-impacts-of-relying-on-desalination/).

Figure 4 Ras Al-Khair Power and Desalination Plant (Flowtite)

Operation and maintenance requirements

Operation and maintenance procedures strictly adhere by well trained and experienced plant operators and maintenance technicians. The implementation of dedicated maintenance regimes involving both scheduled and preventive maintenance programs reduces the possibility of plant breakdown and improves the economy of operation. (Temperley, 2000)

Examples

- Ras Al-Khair Power and Desalination Plant in Saudi Arabia using Multi-Stage Flash (MSF) and Reverse Osmosis (RO) (https://www.swcc.gov.sa/Arabic/Pages/Home.aspx)
- Sorek Desalination Plant in Israel using Reverse Osmosis (RO) (https://www.gov.il/en/departments/general/project-desalination-sorek)

Co Benefit

- *Produces salt through nanofiltration and electrodialysis*
- *Helps protect freshwater habitats*

Disadvantages

- *The capital cost is high*
- *Consumes a large amount of energy*
- *Comprises large scale plant*
- *May wreak havoc on marine ecosystems*

Implementation Cost ($-$$$)	Maintenance costs	is it green
$$$	$$$	No

Temperly T., 2000. Plant Operation, Maintenance and Management. Desalination and Water Resources.

Construction of water reservoirs

Type: Mitigation
Driver: Alternative water sources
Where: Upstream
Function: Water storage for future use

Description of the measure:
A water supply reservoir is an artificial upstream lake that is used to store a large supply of water. The main use of this artificial water body is to collect and store excess water from rainfall, river discharge or surface run-off. The stored water is used in times of drought as water supply for households and industrial uses and allows an overall optimization of the year-round water availability. The water can be piped through gravity and generate hydroelectricity using turbines to a downstream area. Reservoir help to control flooding as well by limiting the amount of water discharged downstream.

- **Short-term effects**

Household and industry can use the stored water from the reservoir for various purposes. Water reservoirs can ensure a constant water supply, even during the dry season or in times of drought and water scarcity.

- **Long-term effects**

Groundwater extraction can be reduced by constructing the water reservoirs as water users will rely on groundwater less. This prevents the drawdown of the water table. Hence, the land subsidence process can be slowed down.

Operation and maintenance requirements

Inspections and maintenance should be performed by specialized technician or engineer. It has to be performed frequently to control the water quality as changes in water quality will have a detrimental effect on the overall water availability.

Figure 5 East Branch Reservoir (Wikipedia)

Examples
There is an abundance of water reservoirs around the world with various uses.

- Aswan Dam, Egypt to supply water for irrigation, regulate floods, protect from frequent drought, and produce electricity: (https://www.britannica.com/topic/Aswan-High-Dam)
- Waduk Cirata, Purwakarta to provide hydroelectricity power, flood control, water supply, and irrigation.(https://jabarprov.go.id/index.php/potensi_daerah/detail/193)

Co Benefit

- *Possibility to generate electricity*
- *Recreational uses*
- *Flood control*

Disadvantages

- *Comprises large area / social considerations*

Implementation Cost ($-$$$)	Maintenance costs	is it green
$-$$$	$	yes

Water neutral industry (+urban) program

Type: Mitigation
Driver: Alternative water sources
Where: Nearby industry and urban areas
Function: Reuse of wastewater (water reclamation)

Description of the measure:
The water neutral industry is a program to develop an industry to capture, treat and reuse water locally so no ground water extraction is required. This program as a step towards stopping groundwater extraction and reducing land subsidence while simultaneously promoting sustainable and circular economic growth by creating incentives to optimize water supply and management systems based on rain water harvesting, storage, conveyance, reuse and recycling. This program is an integration of several measures to store and reuse more water. In the future, it will also create an eco-friendly zone.

- **Short-term effects**

Household and industry can use the stored water for various purposes. The stored water ensures the water availability in the area in times of water scarcity and drought.

- **Long-term effects**

Wastewater in the industrial area can be used effectively while the fresh groundwater is used only for limited purposes. Land subsidence will slow down in consequence of the depletion of the groundwater extraction. It will also help to achieve Zero Liquid Discharge (ZLD) in the area and as the result, the cost related to waste management can be reduced.

Figure 6 Water as Leverage, Semarang

Operation and maintenance requirements
Maintenance for each measures should be performed by each specialized technician or engineer. It has to be performed frequently to control the water quality.

Examples

- Kawasan Industri Suryacipta Karawang (https://investasi.kontan.co.id/news/surya-semesta-resmikan-sistem-pengolahan-air-limbah-di-kawasan-industri-karawang)
- Water Neutral Industry Program - Water as Leverage, Semarang

Co Benefit

- *Reduces CO2 emissions from reduction of diesel-based water pumping*
- *Secures groundwater resources by reducing groundwater extraction*

Disadvantages

- *Requires enforcement*
- *Comprises large area for retention area*

Implementation Cost ($-$$$)	Maintenance costs	is it green
$-$$$	$$	yes

Rainwater harvesting (RWH)

Type: Mitigation
Driver: Alternative water sources
Where: Nearby industry and urban areas

Description of the measure:

Rainwater harvesting (RWH) is a method to collect the run-off from any surface in order to store it for later use. There are some techniques that can be used for RWH, such as: surface runoff harvesting, roof-top rainwater harvesting (RRH), dams, underground tanks, rain saucers, barrage, slopes, trenches, or rain barrels. The harvested water can be used for agriculture, industry, or domestic use. A water purifier needs to be installed to produce potable water. Harvesting rainwater allows the use of a natural resource instead of discharging it towards the sea. RWH depends largely on weather conditions and therefore its application is seasonal and only effective where rainfall is high or evenly distributed.

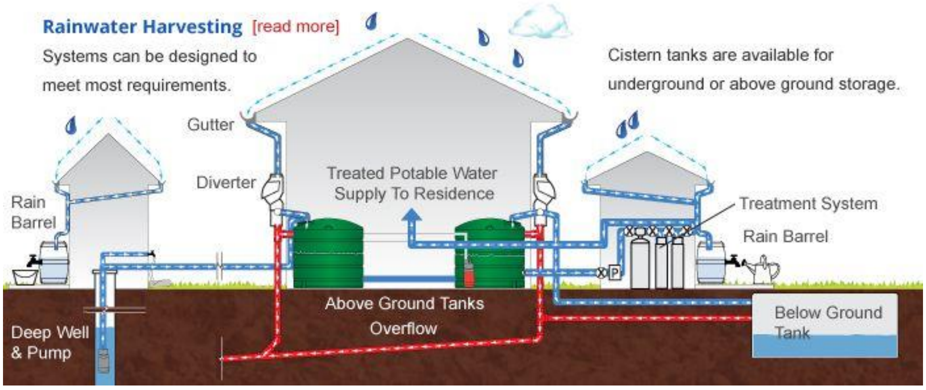

Figure 7 Rainwater Harvesting (Greenhouse engineering)

- **Short-term effects**

Household and industry can use the stored rainfall water for various uses. However, the volume of stored water depends greatly on the rainfall frequency and intensity.

- **Long-term effects**

This measure helps to reduce the groundwater extraction and slow down the land subsidence. However, household and industry may not rely on the RWH fully due to the inconsistency of the water availability through the years. Hence, the complementary use of RWH and groundwater extraction may be implemented.

Operation and maintenance requirements

For small-scale use, RWH is easy to maintain. Maintenance for larger-scale use may be performed by technicians or engineers. It has to be performed frequently to prevent interruption of the system.

Examples

- 40% of Thailand's rural population utilizes rainwater harvesting (Saladin, 2016)
- Frankfurt Airport rainwater harvesting system (Trautner, 2001)

Co Benefit

- *Flood control*

Disadvantages

- *Unpredictable rainfall*
- *Storage limits (depends on type of the techniques)*

Implementation Cost ($-$$$)	Maintenance costs	is it green
$-$$$	$	yes

Saladin, M., 2016. Rainwater Harvesting in Thailand - learning from the World Champions.
Trautner, H.J., 2001. Rainwater utilization at the Frankfurt Airport.

Construction of infiltration basin

Type: Mitigation
Driver: Excess groundwater extraction
Where: Upstream and downstream
Function: Stores surplus surface water

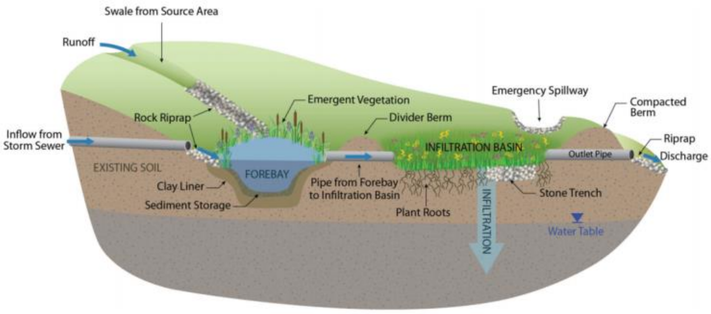

Figure 9 Infiltration basin (Geosyntec)

Figure 9 Rapid infiltration basins, Orlando, Florida (USGS

Description of the measure:

An infiltration basin is an artificial pond that is designed to infiltrate surface run-off through permeable soils into the unconfined aquiver. It differs from water reservoirs or a retention basin in that it is designed to store excess water underground instead of in a permanent pool of water. The infiltration basins may be less effective in areas with high groundwater levels, compacted soils, high levels of sediment in stormwater, or high clay soil content (Urbona, 1998). Additionally, infiltration basins must not be built nearby industrial sites where spills of toxic material may occur (Blick et al., 2004). This will lead to groundwater contamination.

- **Short-term effects**

Short-term, infiltration basins can minimize the rainfall run-off on the surface area. Henceforth, it will reduce the risk of flooding and downstream erosion.

- **Long-term effects**

The infiltration basin helps to rise the groundwater level, and play an important role to affect the deformation features. As a consequence, this will prevent the land subsidence.

Operation and maintenance requirements

Maintenance has to be performed frequently to inspect bottom of the basin and remove any sediment.

Examples

- Rapid infiltration basins, Orlando, Florida (https://www.usgs.gov/media/images/rapid-infiltration-basins-recharge-groundwater-florida)

Co Benefit

- *Flood control*
- *Prevents downstream erosion*

Disadvantages

- *Chance of groundwater contamination*
- *Fines may reduce the infiltration rate*

Implementation Cost ($-$$$)	Maintenance costs	is it green
$	$	yes

Urbona B.R., 1998, Urban Runoff Quality Management. American Society of Civil Engineers.
Blick, Sandra A. & Kelly, Fred & Skupien, Joseph J.. 2004. New Jersey stormwater best management practices manual.

Groundwater extraction policy and policy enforcement

Type: Mitigation
Driver: Excess groundwater extraction
Where: Upstream and downstream
Function: Reduce groundwater extraction through regulation

Description of the measure:

Policy is a set of ideas or a plan of principles to guide decisions and achieve rational outcomes. In the case of groundwater, when one user uses more, less remains for the others. When no regulatory frameworks exists users have no reasons that incentivize them to restrain or reduce their resource use; the self-interest of the individual users then easily leads to over-exploitation (Hoogesteger, 2017). Hence, groundwater policy is an essential instrument to reduce the groundwater extraction. There are some examples of groundwater policy, such as tax procedures for private companies who use groundwater source, restriction policy for groundwater extraction, and groundwater use restriction by zoning. The groundwater policy needs to be assessed with policy reinforcement to ensure compliance the procedures. Policy reinforcement can be implemented by monitoring the policy implementation and giving incentives to the people.

- **Short-term effects**

Individual users or private companies tend to find an alternative for the groundwater extraction. This will induce a cultural shift in the society.

- **Long-term effects**

The groundwater extraction policy helps to reduce the groundwater extraction through regulations. This will slow down the land subsidence rate in the area.

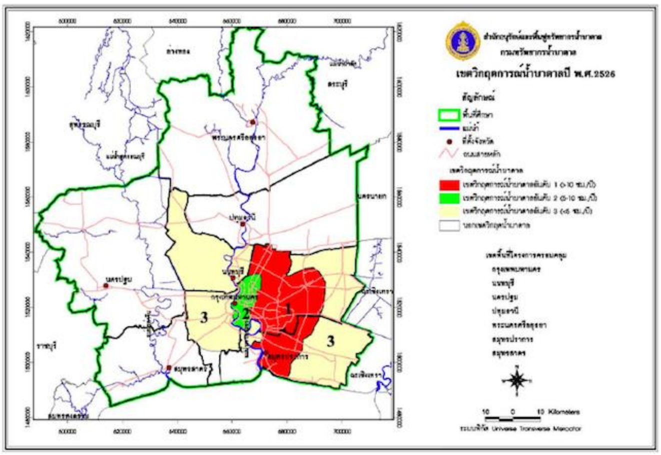

Figure 10 Groundwater use restriction by zoning in Bangkok, Thailand (Terra BKK)

Operation and maintenance requirements

Policy implementation needs to be monitored frequently.

Examples

- Groundwater use restriction by zoning in Bangkok, Thailand (Buapeng, 2008)
- Restriction policy for groundwater extraction in Tokyo, Japan (Sato, 2006)

Co Benefit

- *Increases the likelihood of more sustainable methods being used*

Disadvantages

- *Policy is difficult to be monitored*
- *Requires a cultural shift*

Implementation Cost ($-$$$)	Maintenance costs	is it green
$	$	no

Hoogesteger, J. and Wester, P., 2017. Regulating groundwater use: The challenges of policy implementation in Guanajuato, Central Mexico. *Environmental Science & Policy*, *77*, pp.107-113.

Buapeng, S. and Wattayakorn, G., 2008. Groundwater Situation in Bangkok and Its Vicinity. *Hydrological changes and management from headwater to the ocean, At Kyoto Garden Palace, Kyoto, Japan*, pp.1-3.

Sato, C., Haga, M., & Nishino, J., 2006. Land subsidence and groundwater management in Tokyo. *International Review for Environmental Strategies*, *6*(2), 403-424.

Land subsidence monitoring

Type: Mitigation / Adaptation
Driver: Land subsidence
Where: Upstream and downstream
Function: Monitor the land subsidence rate in the area

Description of the measure:

Monitoring land subsidence is an essential step to track the land subsidence rate in an area. The aim of this measure is to improve understanding of the processes responsible for changes in the elevation of the land's surface. Monitoring the land subsidence could be measured from land surface elevations. The most frequent techniques to measure elevation-change are interferometric synthetic aperture radar (InSAR), continuous GPS (CGPS) measurements, campaign global positioning system (GPS) surveying and spirit-leveling surveying. While for the aquiver-system compaction is measured by using extensometers. The extensometers make the measurement at a specific depth of interest is possible. The most precise measurement tend to be made using spirit-leveling surveys and extensometers, while the least precise are using GPS surveying. (https://www.usgs.gov/centers/ca-water-ls/science/measuring-and-monitoring)

- **Short-term effects**

It allows us to determine the land level in an area in a specific time. The land level data should be collected in a dataset for further analysis.

- **Long-term effects**

The data collection through several years in an area could be processed to determine the land subsidence rate and forecast the land level in the future. This will help to assess decision-making for a mitigation or prevention measure.

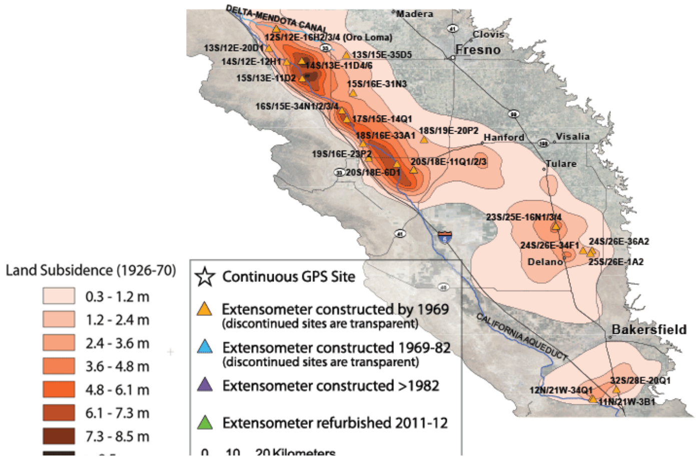

Figure 11 Land subsidence monitoring in San Joaquin Valley (USGS)

Operation and maintenance requirements

The operation should be performed by trained engineers or technicians.

Examples

- Land subsidence monitoring in Semarang using synthetic aperture radar (SAR)
- Land subsidence monitoring in the San Joaquin Valley (https://www.usgs.gov/centers/ca-water-ls/science/land-subsidence-san-joaquin-valley?qt-science_center_objects=0#qt-science_center_objects)

Co Benefit

- *Increases the likelihood of more sustainable methods being used*

Disadvantages

- *Policy is difficult to be monitored*
- *Requires a cultural shift*

Implementation Cost ($-$$$)	Maintenance costs	is it green
$	$	no

Conjunctive use of surface water and groundwater as water source

Type: Mitigation
Driver: Excess groundwater extraction
Where: Upstream and downstream
Function: Provides water alternative

Description of the measure:

The increasing of water scarcity problems requires the adoption of a double approach of water supply management. The conjunctive use of both surface and groundwater is one of the strategies of water supply management. This method has to be considered to optimize the water resource development, management, and conversation. It helps to consider the water resource as a one system and would avoid a water resource development approach focused only on surface water. Since the surface water has poorer-quality compared to the groundwater, it still may require extensive water treatment. This measure can also provide a smooth transition from the groundwater to surface water consumption, i.e. the amount of groundwater used decrease while the surface water use slowly increases.

- **Short-term effects**
  By increasing the amount of sources for water the management can be better optimized

- **Long-term effects**
  Groundwater extraction can be reduced but not as significant as the water resource development approach focused only on surface water. It helps to reduce the land subsidence rate in the area.

Figure 12

Operation and maintenance requirements

The surface water quality needs to be maintained frequently.

Examples

- Upper Bangladesh, Delta Plain (Faneca Sanchez et al., 2015)
- Southern California and southern San Joaquin Valley, United States (Zhang, 2015)

Co Benefit

- *Flood control*

Disadvantages

- *High-quality groundwater is mixed with poorer-quality surface water*
- *May require extensive treatment*

Implementation Cost ($-$$$)	Maintenance costs	is it green
$$$	$-$$	no

Faneca Sànchez, M., Bashar, K., Janssen, G., Vogels, M., Snel, J., Zhou, Y., ... & Oude Essink, G., 2015. SWIBANGLA: Managing salt water intrusion impacts in coastal groundwater systems of Bangladesh.

Zhang, X., 2015. Conjunctive surface water and groundwater management under climate change. *Frontiers in Environmental Science*, *3*, p.59.

Construction of dikes

Type: Adaptation
Driver: Rising water level / land subsidence
Where: Downstream, specifically towards the coast
Function: Prevents the land from flooding

Description of the measure:

A dike is an artificial structure along the river bank or low lying coast to prevent water from inundating the hinterland. As the land subsides, the water level, at the river or sea, will become higher than the land level. As a consequence, the water will able to flood the land area. Dike construction will temporarily prevent this tragedy to occur.

- **Short-term effects**

Land area is protected from the inundation from river or sea.

- **Long-term effects**

Continued land subsidence and increase water levels as cause by climate change make it so that dikes need to be reinforced as the system changes.

Figure 13 A levee in Mississippi (Mississippi Valley Division, U.S. Army Corps of Engineers)

Operation and maintenance requirements

The repair and maintenance of dike must be performed periodically in order to enhance the structural stability and durability of the structure.

Examples

- Coastal dikes in Kapuk Naga Indah Island 2A,Jakarta
- Mississippi River and Tributaries (MR&T) Leeves in Mississipp, United States (https:// www.mvd.usace.army.mil/About/Mississippi-River-Commission-MRC/Mississippi-River-Tributaries-Project-MR-T/Levee-Systems/

Co Benefit	***Disadvantages***
• *Allows multi-functional developments*	• *It requires significant areas of land*

Implementation Cost ($-$$$)	Maintenance costs	is it green
$$$	$	no

Construction of polder system

Type: Adaptation
Driver: Rising water levels / land subsidence
Where: Downstream, specifically towards the coast
Function: Prevents the land from flooding

Figure 14 Zoertemeer (Wikipedia)

Description of the measure:

A polder is a low lying area enclosed by flood defenses that requires a drainage system to control the water levels inside the system (Lendering, 2015). As the land subsides, the water level will be higher than the land area. Polder systems prevent the surrounding water to enter the land area. It must be noted that a polder lies below the surrounding water level. Both the investment cost and the flood risk are determined by the flood defense level. To control the water level inside the polder, it is necessary to install drainage systems.

- **Short-term effects**

Land area is protected from the inundation from river or sea.

- **Long-term effects**

As the land subsidence continues to occur, the water level will also continue to rise. Strengthening and increasing flood defense height need to be performed at some point in the future.

Operation and maintenance requirements

The operation and maintenance of dike must be performed periodically in order to enhance the structural stability and durability of the polder.

Examples

- Polder in Zoertemeer in the Netherlands (https://www.2xu.nl/resources/de_leyens/KA15100NL01v01_pg-de-leyens.pdf)
- Banger Polder in Semarang, Indonesia (https://jatengprov.go.id/beritadaerah/pengelolaan-polder-banger-minimalisir-rob-dan-banjir-di-semarang/)

Co Benefit	***Disadvantages***
▪ *Lower environmental impact*	• *Needs additional drainage systems* • *The flood protection surrounding the polder must be very safe due to consequences being large*

Implementation Cost ($-$$$)	**Maintenance costs**	**is it green**
$$$	$	no

Raising levels of railroads and roads

Type: Adaptation
Driver: Land subsides in the area
Where: Flood-prone areas
Function: Prolong functionality

Description of the measure:

Land subsidence increases the consequences of tidal, fluvial and pluvial flooding. An often-used strategy to prevent these floods is to raise the levels of roads and railroads. As a consequences, the houses and buildings will locate below the roads level. Heavy rainfall will jeopardize the civilization, since the surface run-off tends to flow inside the houses and buildings. Cost to raise the road is also relatively higher compared to constructing dikes.

- **Short-term effects**

Tidal inundation will not able to flood the land area.

- **Long-term effects**

As the land continues to subside, the water level will also continue to rise. Railroads and roads need to be adjusted with the water level in the future. It will cause houses and buildings level locate far below the road level.

Figure 15 Raising levels of roads in Kudus-Demak road, Indonesia (top, Tribun Jateng) and Pekalongan, Indonesia (bottom, Tribun Jateng)

Operation and maintenance requirements

Maintenance need to be assessed every specific period of time to fix the road and to adjust the road level with the water level in the future.

Examples

- Raising road level in Tanjong Priok, Jakarta Utara, Indonesia (https://koran.tempo.co/read/metro/50672/meninggikan-jalan-menghadang-air)
- Raising grades for the road level in Pekalongan, Jawa Tengah, Indonesia (Marfai and Cahyadi, 2017

Co Benefit

- -

Disadvantages

- *The capital cost is high*
- *Houses and buildings level need to be adjusted as well*

Implementation Cost ($-$$$)	Maintenance costs	is it green
$$$	$	no

Marfai, M.A. and Cahyadi, A., 2017. Dampak bencana banjir pesisir dan adaptasi masyarakat terhadapnya di kabupaten Pekalongan.

Integrated Coastal Zone Management (ICZM)

Type: Adaptation
Driver: Degraded fisheries habitats, lack of understanding of the economic contribution of coastal resources to society
Where: Downstream
Function: Prevents disasters, alleviate the impacts, and promote sustainable development of the coastal zone

Description of the measure:

Integrated Coastal Zone Management (ICZM) is a planning and coordinating process for the management of the coast using an integrated approach, with respect to all sectors. The main goals of ICZM are maintaining the functional integrity of the coastal resource systems, reducing resource-use conflicts, maintaining the health of the environment, and facilitating the progress of multisectoral development (Thia-Eng, 1993). There are several types of integration that occur within ICZM; integration among sectors (e.g. tourism, fisheries, port companies), between land and water element of the coastal zone, among level of government, between nations, and among disciplines (scientific, cultural, traditional, political, and local expertise) (Cicin-Sain, 1993). The involvement of all parties of interest is the main distinguishment of this measure. ICZM is the complete integration of all measures that combines whole aspects of the coastal zone from various approaches. Henceforth, this measure should be taken into consideration.

- **Short-term effects**

ICZM will help to achieve multisectoral economic development in the area. An appropriate coastal environment for natural habitat and species will be developed as well.

- **Long-term effects**

As the land subsidence rate increases every year, the coastal area will be more vulnerable to coastal hazards. ICZM will protect the coastal area against these hazards. It balances environmental, economic, social, cultural, and recreational objectives.

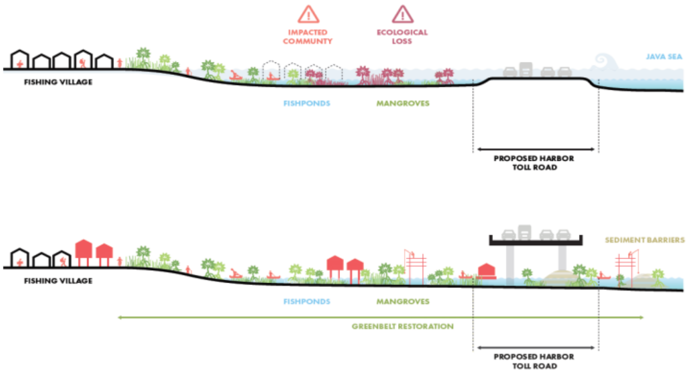

Figure 16 Resilient kampungs adjacent to riverways or coastal area ©One Architecture & Urbanism

Operation and maintenance requirements

Evaluation needs to be performed over a period of time. It is a crucial part of the process. It allows to improve the effectiveness of ICZM in the area.

Examples

- Resilient kampungs adjacent to riverways or coastal area in Semarang, Indonesia
- ICZM in Srilanka since 1983 (Sadacharan, 2011)

Co Benefit

- *Facilitates sustainable economic growth based on natural resources*
- *Conserves natural habitats and species*
- *Provides a mechanism and tools for resource allocation*

Disadvantages

- *Initiation of the approach requires careful planning from all sectors*
- *Successfulness of ICZM strongly depends on all sectors*

Implementation Cost ($-$$$)	Maintenance costs	is it green
$$$	$$	No

Thia-Eng, C., 1993. Essential elements of integrated coastal zone management. *Ocean & Coastal Management*, *21*(1-3), pp.81-108.

Cicin-Sain, B., 1993. Sustainable development and integrated coastal management. *Ocean & coastal management*, *21*(1-3), pp.11-43.

Sadarchan, D., 2011. Decades of ICZM experiences, Sri Lanka. *Climate of Coastal Cooperation*.

Construction and development of public blue-green infrastructures (BGI)

Type: Adaptation
Driver: Urban flooding
Where: Downstream
Function: Flood resilience

Figure 17 Bandar Rimbayu in Selangor, Malaysia ©Steven Ngu, Andy Lim

Description of the measure:
Blue-green infrastructure (BGI) can be defined as a network of green spaces that provides multiple water-related ecosystem services (Kuei-Hsian Liao, 2019). It is an implementation of socio-ecological practice in the urban area. BGI consists the green spaces; such as parks, urban forests, wetlands or green yards, and water areas; such as waterways, bioretention swales, bioretention basins, or sediment basins. These aquatic green spaces are mainly used for controlling floods, storing the surface run-off, improving the water quality, and supplying the water. BGI also plays a key role in improving ecological connection and mitigating urban heat island effects (UHIE) (Žuvela, 2016).

- **Short-term effects**

BGI provides public services at the district or community level for various purposes.

- **Long-term effects**

BGI plays a critical role in flood management (Brears, 2018). This will help to minimize the land subsidence impact in the area. BGI could cool urban areas as well, through evapotranspiration, shadowing, adjusting emissivity and affecting air movement and heat exchange (Wu, 2019; Gunawardena, 2017).

Operation and maintenance requirements

Maintenance is required to be performed regularly, particularly the aquatic green areas.

Examples

- Yanweizhou Park in Jinhua, China (https://wri-india.org/blog/living-water-integrating-blue-green-and-grey-infrastructure-manage-urban-floods)
- The Arc at Bandar Rimbayu in Selangor, Malaysia (https://www.futurarc.com/project/building-blue-and-green-spaces/)

Co Benefit	**Disadvantages**
▪ *Recreational uses (public spaces)* ▪ *Natural habitats protection* ▪ *Alternative water supply* ▪ *Low-emission zone (LEZ)*	▪ *Requires large areas* ▪ *The capital cost is relatively high*

Implementation Cost ($-$$$)	Maintenance costs	is it green
$$$	$	yes

Awareness raising in dealing with land subsidence

Type: Adaptation
Driver: Land subsides in the area and its impact
Where: Upstream and downstream
Function: Encourages citizens to get involved in dealing with land subsidence

Description of the measure:

Awareness raising aims to inform and educate people regarding an issue with the aim of influencing their behavior and beliefs to achieve a goal. Awareness raining can include but is not limited to: workshops, pamphlet distribution, and dissemination of information via website (JICA, 2019). Awareness raising could be implemented with a top-down strategy, starting from government organizations, stakeholders, to residents.

Short-term effects

The influence of awareness raising is immediate. A small group of early adopters will use newly gained insights to influence others if the campaign is effective.

Long-term effects

Awareness raising activities will create a better understanding of land subsidence causes and impacts. It will result in the acceleration of several processes in the implementation of the countermeasures as peoples understanding increases and public awareness steers decisionmakers to more sustainable operations.

Operation and maintenance requirements

-

Figure 18 Coastal Field School in Demak, Indonesia (Wetlands International)

Examples

- Awareness raising by JICA in Jakarta, Indonesia (https://www.jica.go.jp/english/publications/j-world/c8h0vm0000f60sy3-att/1910_03.pdf)
- Coastal Field School in Demak, Indonesia (https://www.wetlands.org/blog/fishshrimp-farming-coastal-field-school-a-new-hope-for-local-farmers-in-coastal-demak/)

Co Benefit	**Disadvantages**
	▪ *Preparation for the implementation takes time* ▪ *It might lead to no action*

Implementation Cost ($-$$$)	Maintenance costs	is it green
$	-	no

Japan International Cooperation Agency (JICA), 2019. Project for Promoting Countermeasures against Land Subsidence in Jakarta: Establishment of Implementation Committee and Action Plan, and Action Building.

Construction of retention basin

Type: Adaptation
Driver: Flooding in the urban area
Where: Downstream
Function: Flood resilience

Description of the measure:

Retention basin is a permanent artificial pool of water. The main uses of retention basins is to manage flooding and downstream erosion. It is also able to improve the water quality in an adjacent river, lake, or bay. Retention basin is often landscaped with a variety of vegetation. It helps to provide water quality benefits by removing soluble nutrients through uptake (UDFCD, 2010). Retention basin differs from an infiltration basin which is designed to infiltrate stormwater through permeable soils. By integrating it with water treatment plant, the contained water can be used as an alternative water supply.

Figure 19 Trounce Pond in Saskatoon, Saskatchewan, Canada. Figure 20 Waduk Pluit (Berita Satu)

- **Short-term effects**

Retention basins will help to reduce flooding in the area. Retention basins also gives aesthetic benefit to the urban area.

- **Long-term effects**

Retention basin could reduce the impact of the land subsidence, i.e. flood. It helps to manage the flood, particularly in the downstream and coastal area

Operation and maintenance requirements

Regular maintenance is necessary for retention basins. This includes sediment and debris removal, fixing pipes or riser, inspection or repair of critical structural features. Removing debris and sediment can be performed by citizen volunteers, while fixing pipes and repairing structure should be performed by a qualified professional.

Examples

- Trounce Pond in Saskatoon, Saskatchewan, Canada (https://www.saskatoon.ca/community-culture-heritage/neighbourhoods-community-associations/recreational-use-stormwater-ponds)
- Waduk Pluit in Jakarta, Indonesia (https://www.kompas.id/baca/lain-lain/2020/01/17/peran-penting-waduk-pluit-di-jakarta/)

Co Benefit

- *Alternative water supply*
- *Aesthetic benefit*
- *Supports local wildlife*

Disadvantages

- *The capital cost is high*

Implementation Cost ($-$$$)	Maintenance costs	is it green
$$$	$	yes

Urban Drainage and Flood Control District (UDFCD), 2010. Urban Storm Drainage Criteria Manual, Volume 3–Best Management Practices. *Urban Drainage and Flood Control District, Denver, CO.*