Urban Drainage and Sewerage

Zoran Vojinovic

Learning objectives

- After completing this lecture, participants will be able to describe the following;
  – The purpose and importance of urban drainage
  – The effects of urbanization and climate change on urban drainage
  – The different types of drainage and sewerage systems

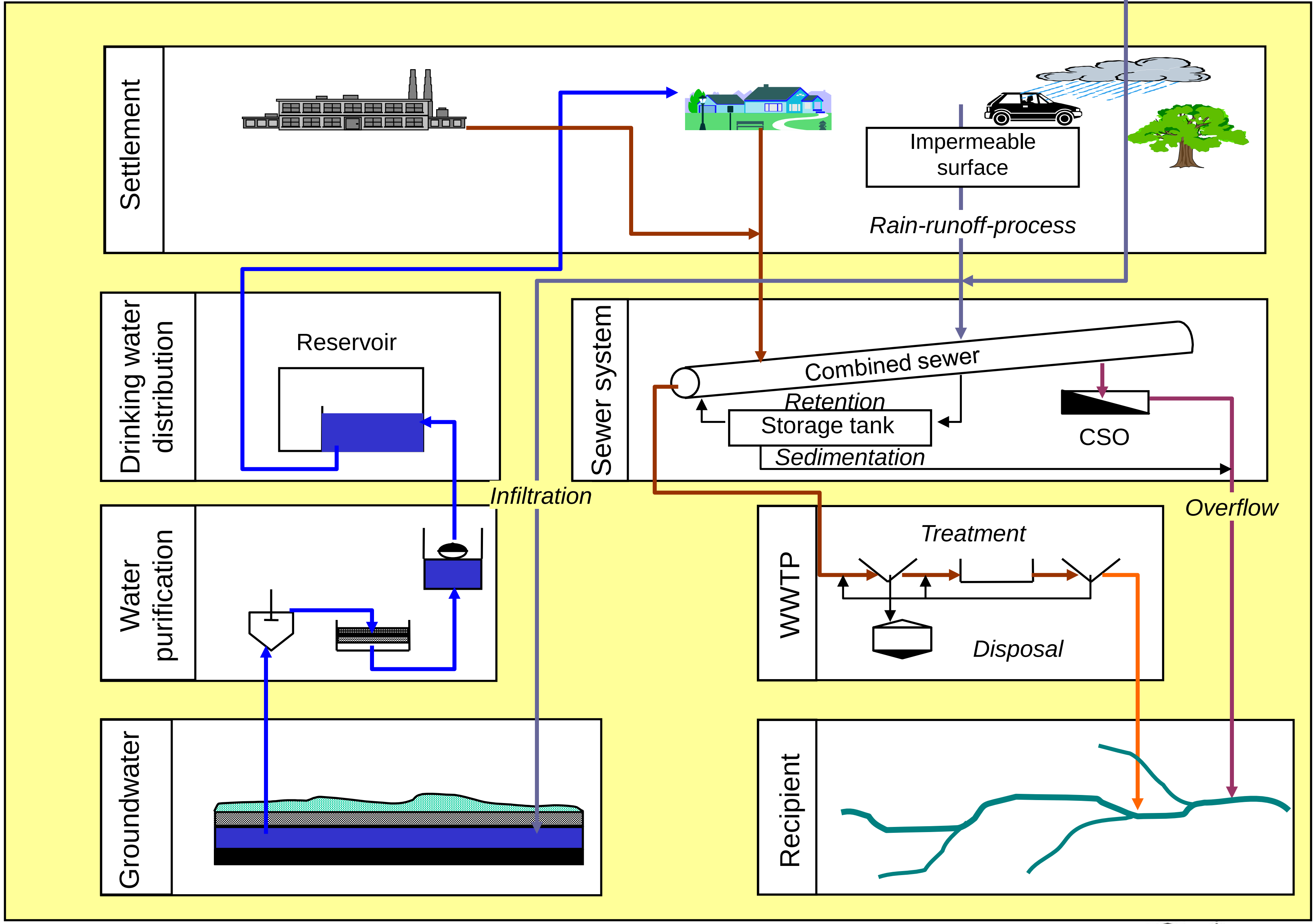
Outline

- Introduction
- Traditional or conventional systems: Combined, Separate, Simplified, Solid free, Pressurised, Vacuum, Open channel drains
- Green infrastructure systems (a.k.a Nature-Based Solutions)

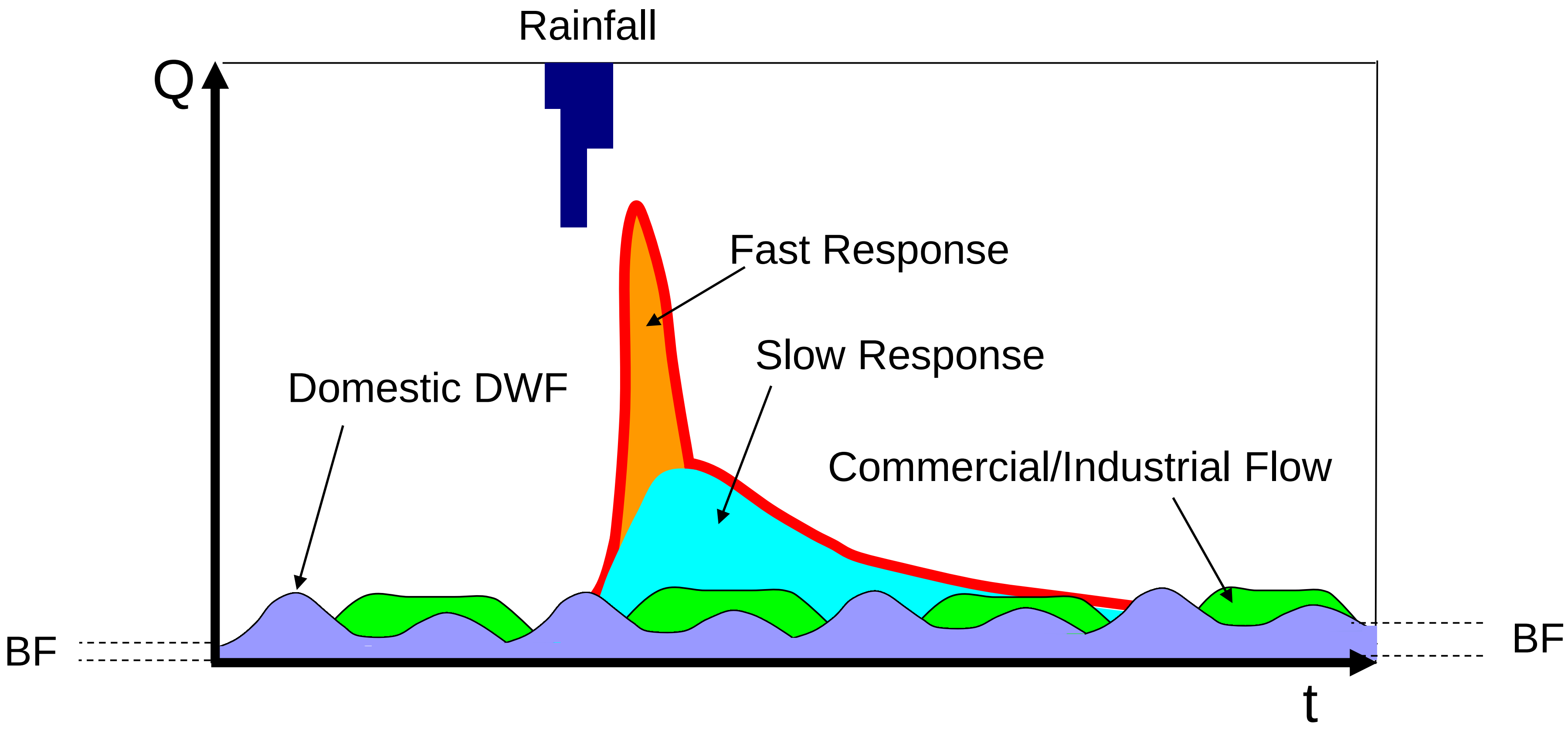
Introduction

What is the purpose of Urban Drainage and Sewerage?

Introduction



Introduction



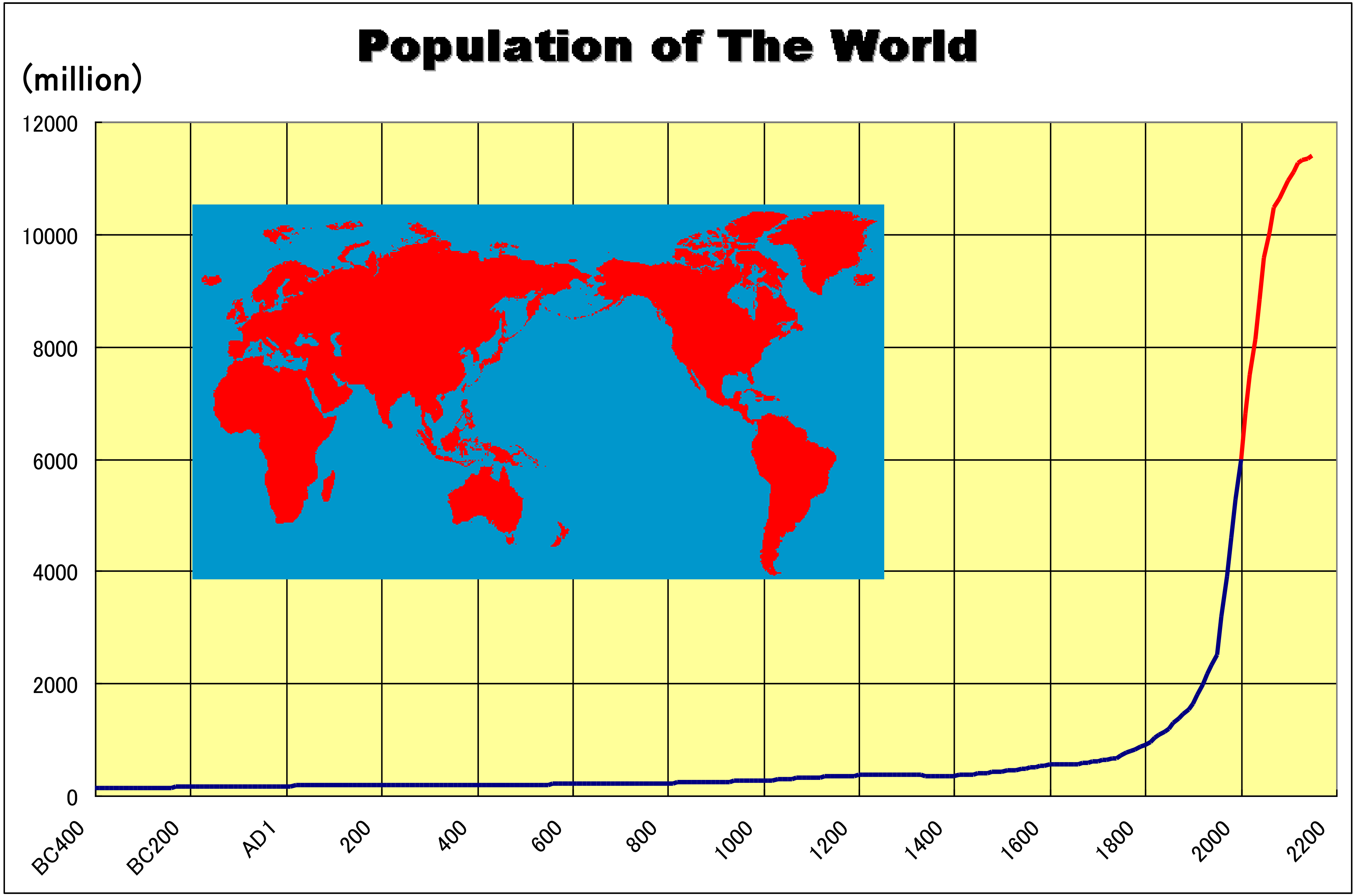
Introduction

Issues and Challenges

Introduction

Introduction

Introduction


Population of The World
(million)
12000
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8000
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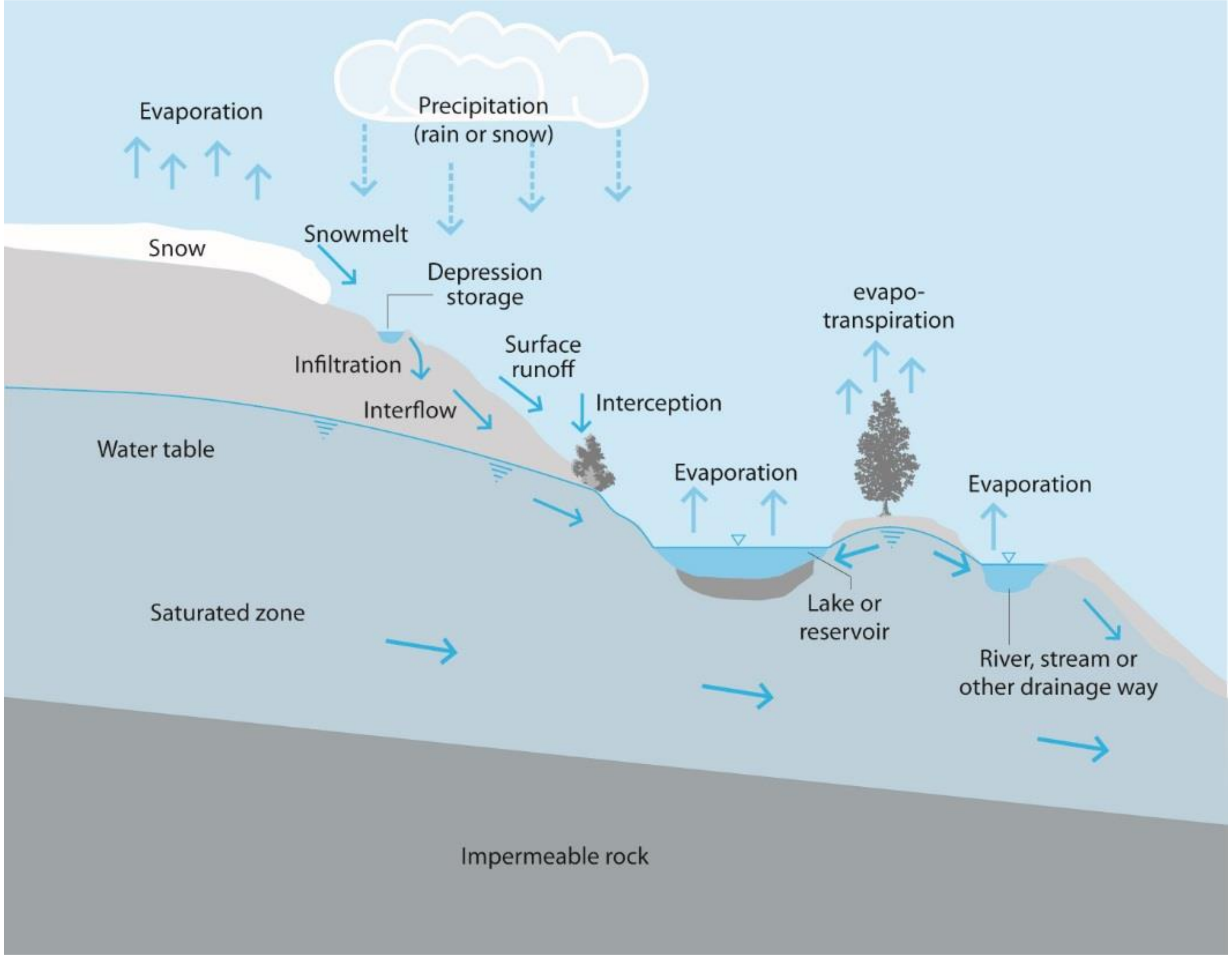
Introduction



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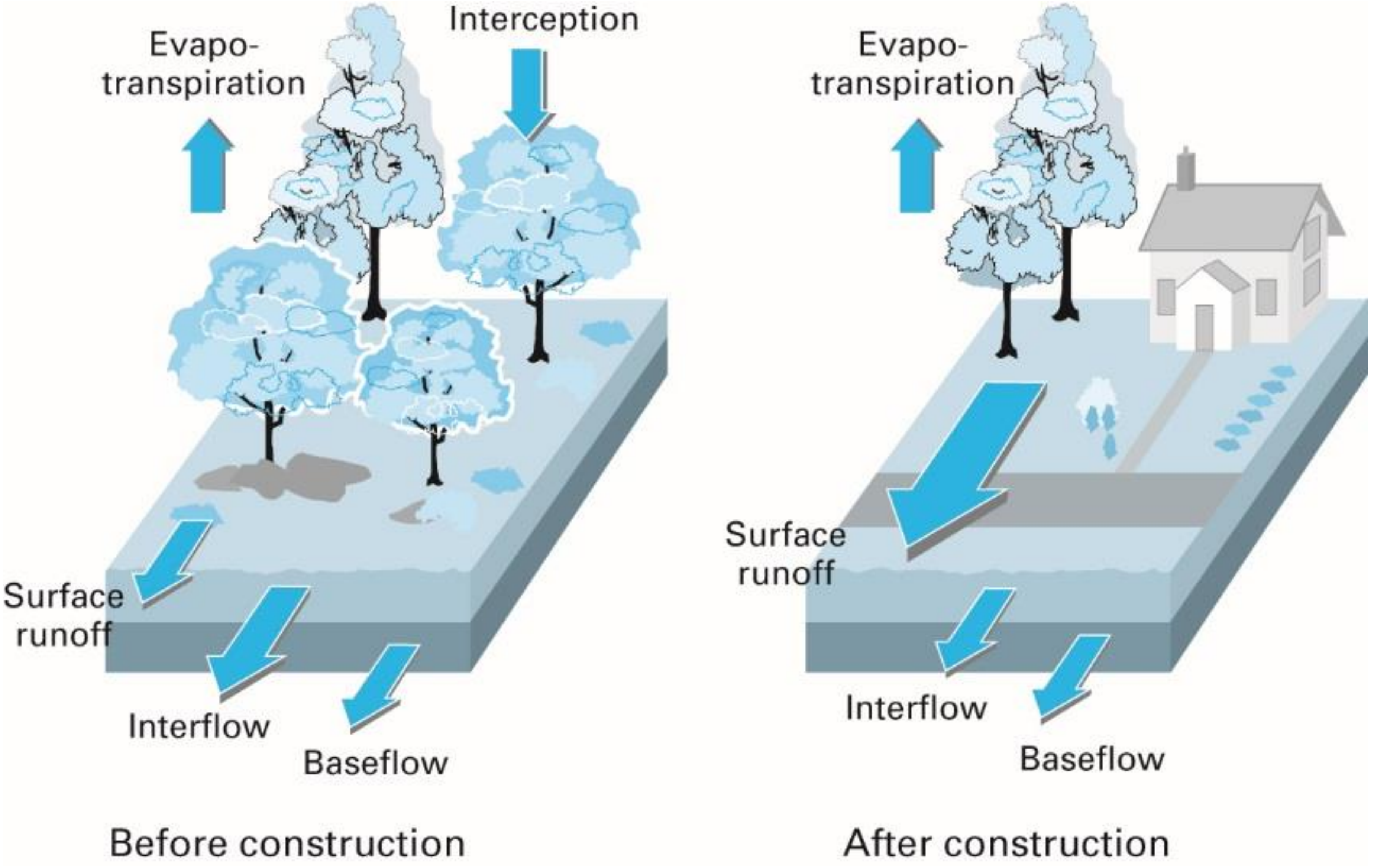

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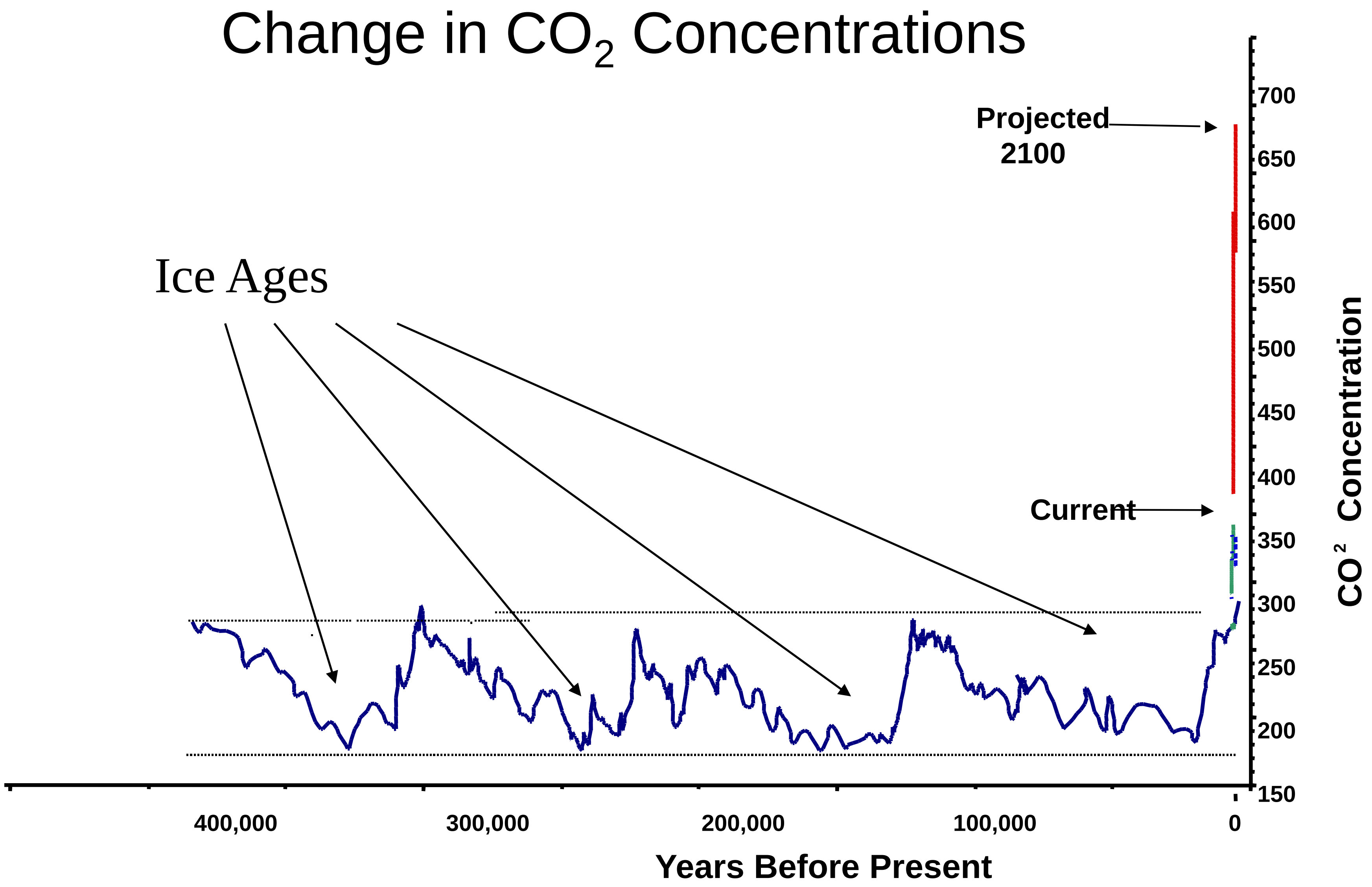

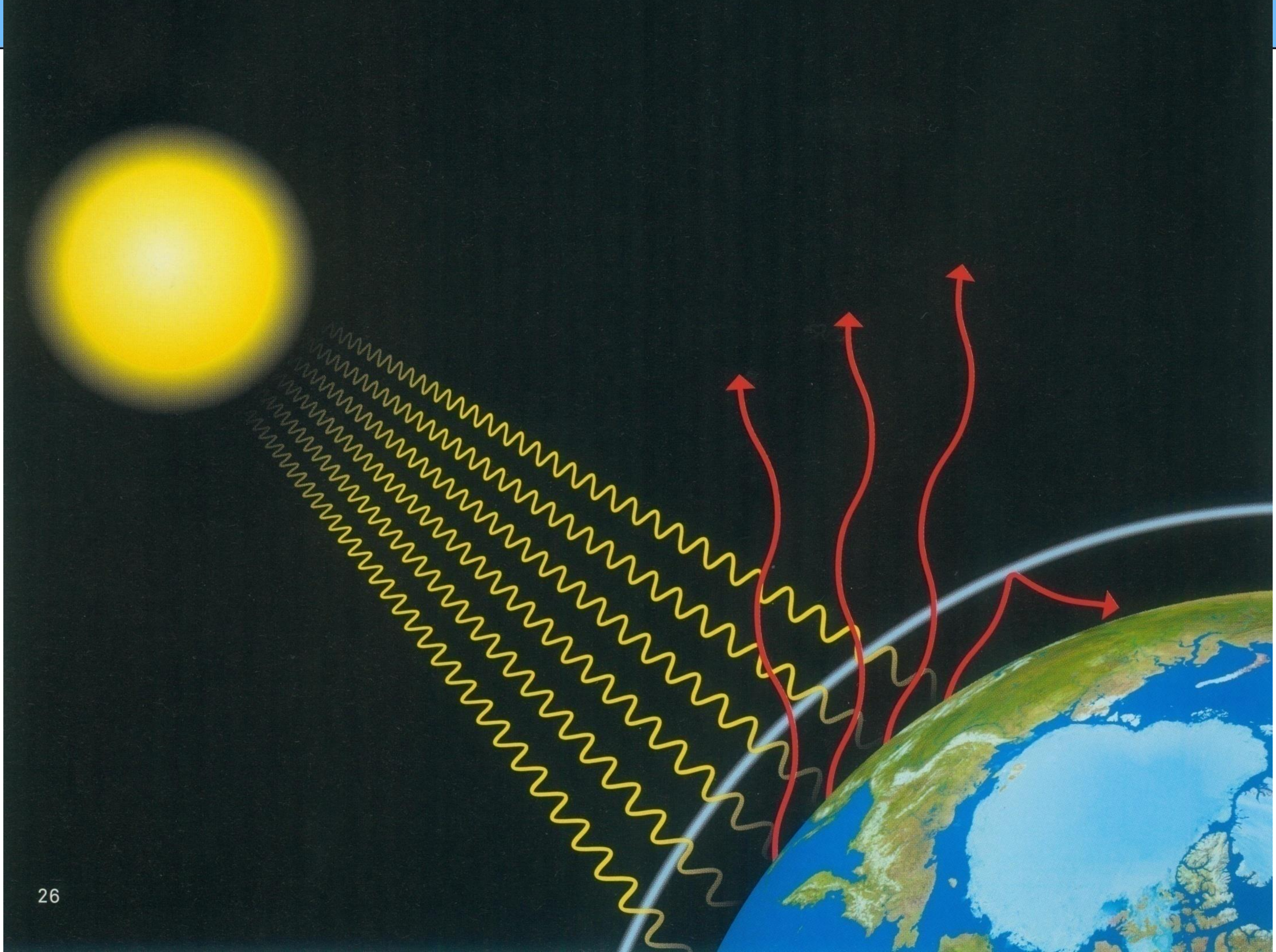
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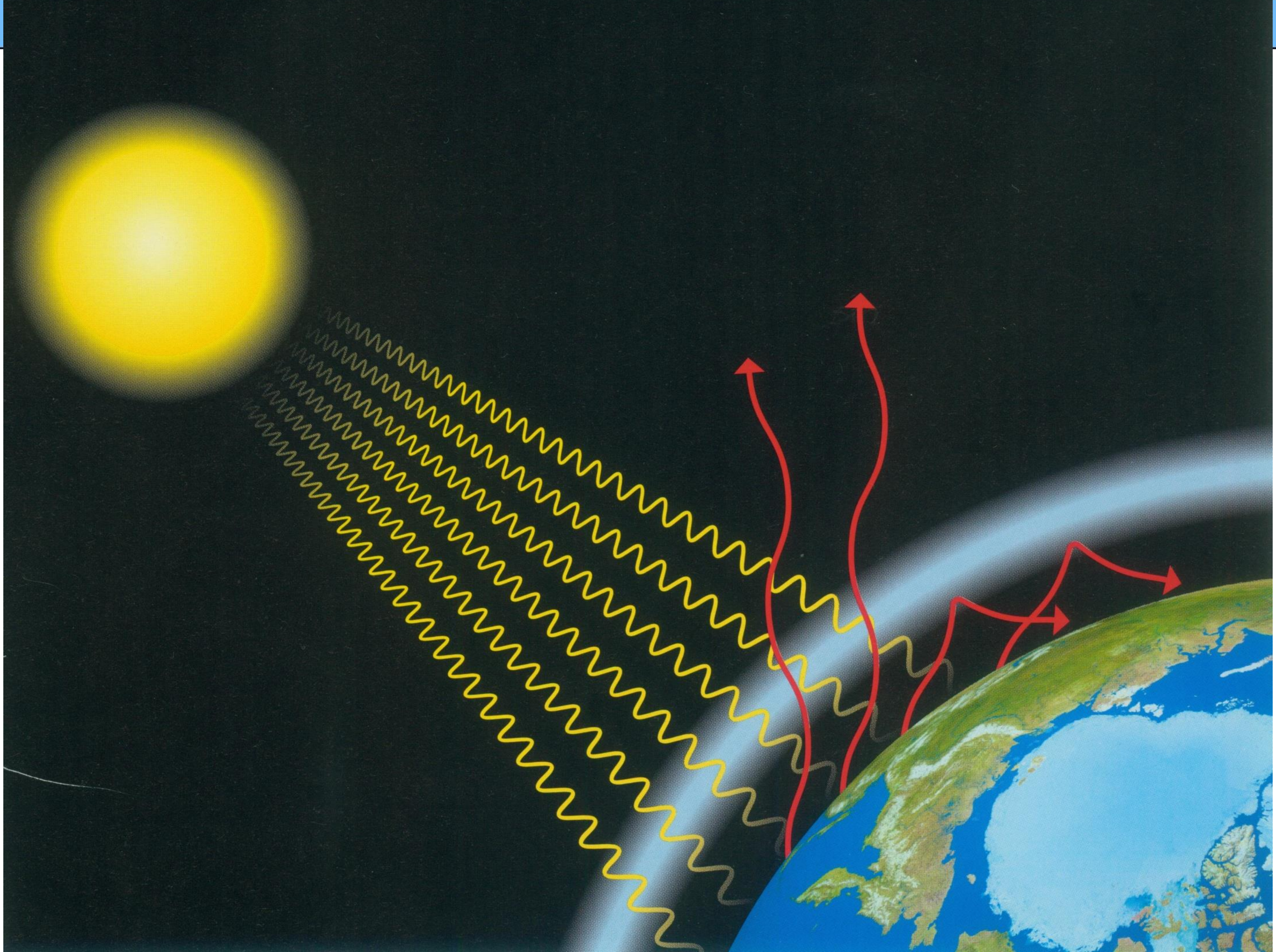
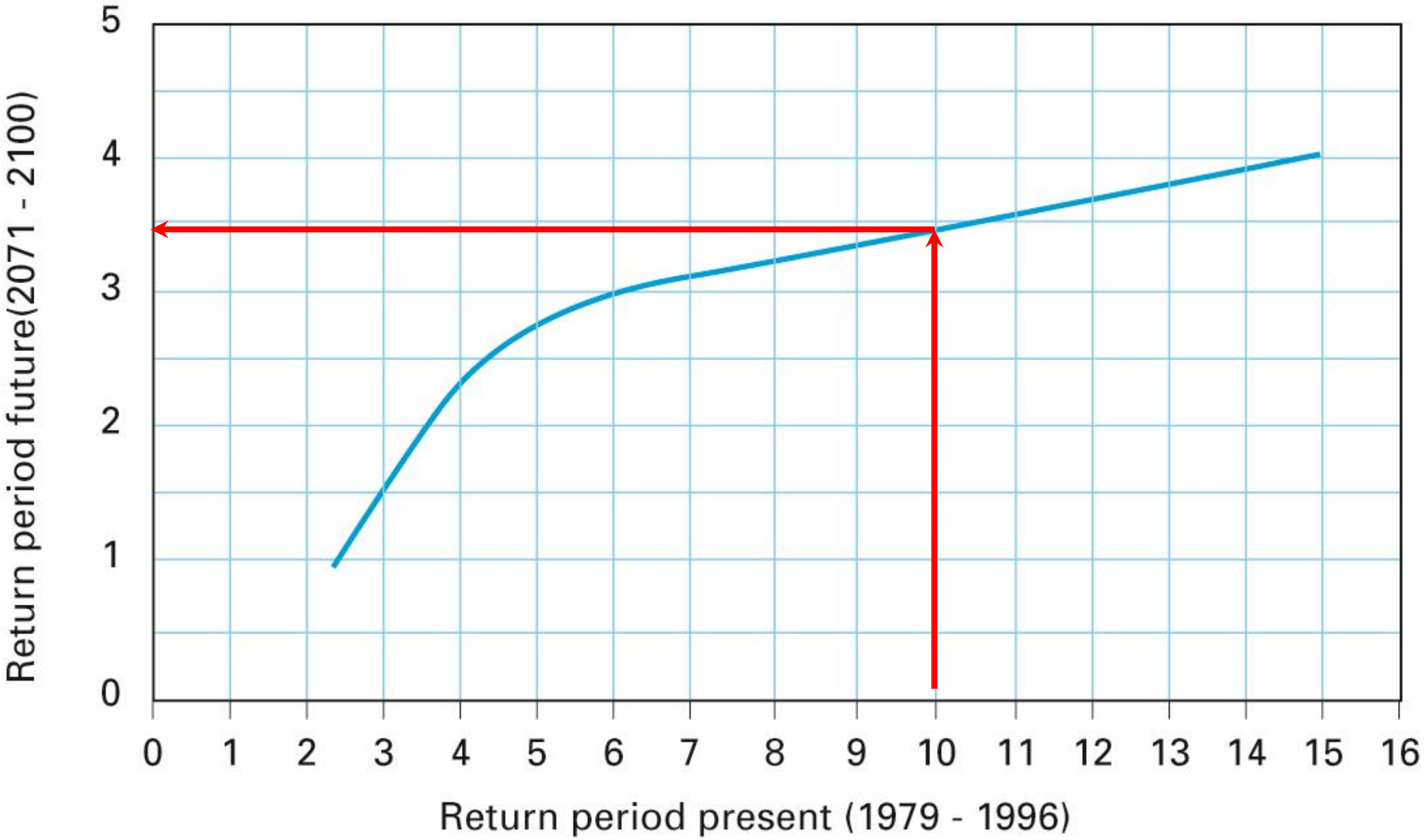


Introduction

Urban Drainage – Climate change example of issues



Types of systems

- In terms of the collection:
  - Combined – storm and wastewater together
  - Separate – storm and wastewater apart
  - Above ground/below ground
- In terms of the transport:
  - Gravity
  - Pressure
  - Vacuum
- In terms of the “materials used”:
  - “Grey”
  - “Green/Blue”, a.k.a., Nature-Based Solutions

Types of sewer systems

- Combined sewers
- Separate sewers
- Simplified sewers
- Solid free sewers
- Pressurised sewers
- Vacuum sewers
- Open channel drains

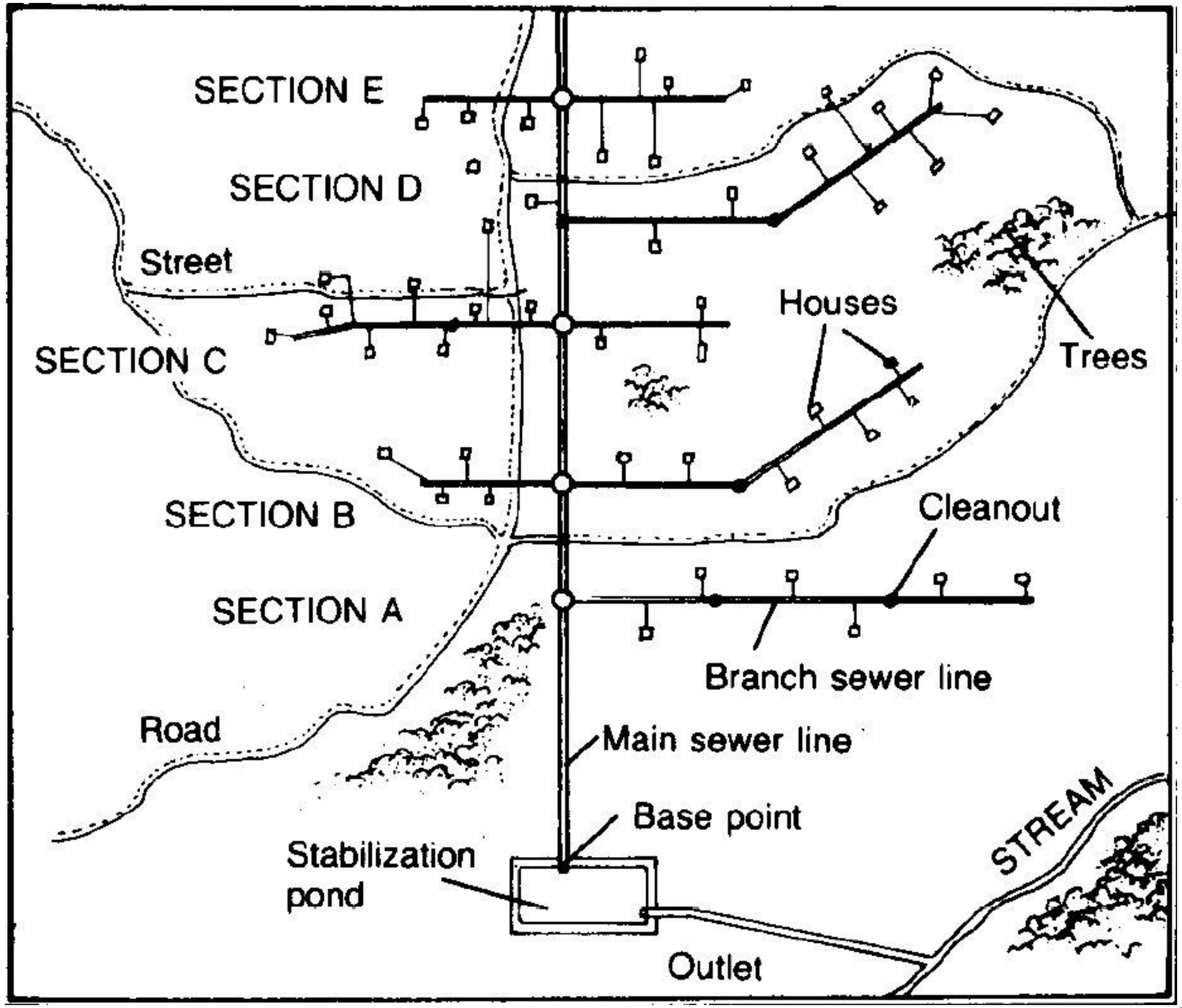
- *“Green infrastructure systems”*

Combined sewerage

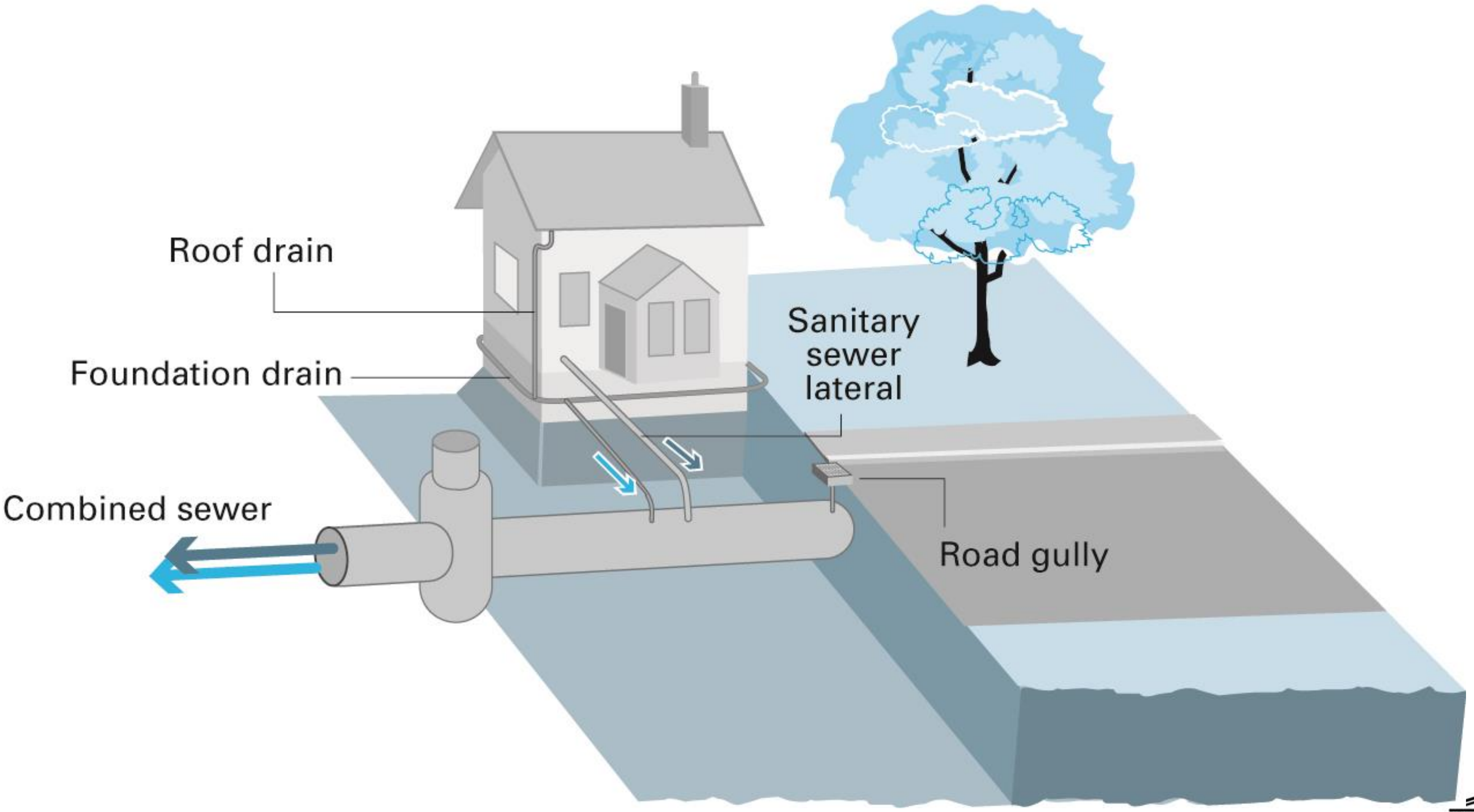
- Large networks of underground pipes, mostly in urban areas.
- Collection of blackwater, greywater and stormwater.
- Do not require on-site pre-treatment or storage of the wastewater
- Discharge either into the WWTP or into a water body

Combined sewerage

- Consisiting of three lines
- Main line (primary): the centre of the system, all other lines empty into it.
- Branch lines (secondary): extend from the main.
- House laterals (tertiary): bring wastwater from the houses to the branch lines.



Combined Sewers

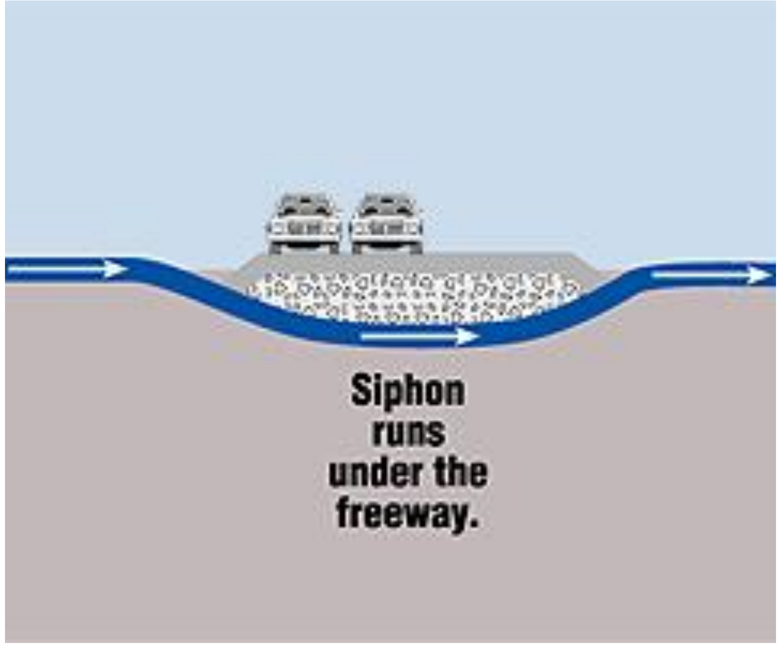


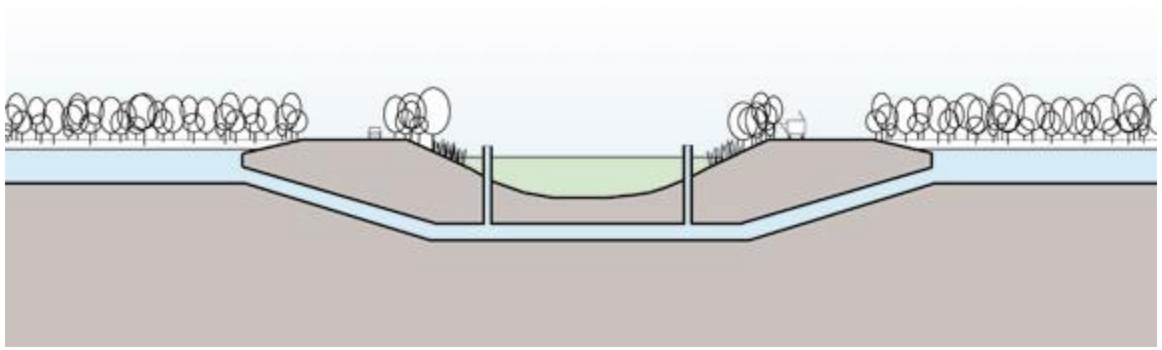
Combined sewers – design aspects

- **Self-cleansing velocity** (i.e. a flow that will not allow particles to accumulate), generally obtained with a minimal flow of 0.6 to 0.75m/s
- When the required slope cannot be maintained – **pumping**
- **Laid beneath roads**, at minimal depths of 1.5 to 3m
- **Access manholes** are set at regular intervals, at pipe intersections, at changes in pipeline direction, and at drops
- **Inverted siphons** – under structures, rivers, etc.

Combined sewers – design aspects

- Inverted siphons





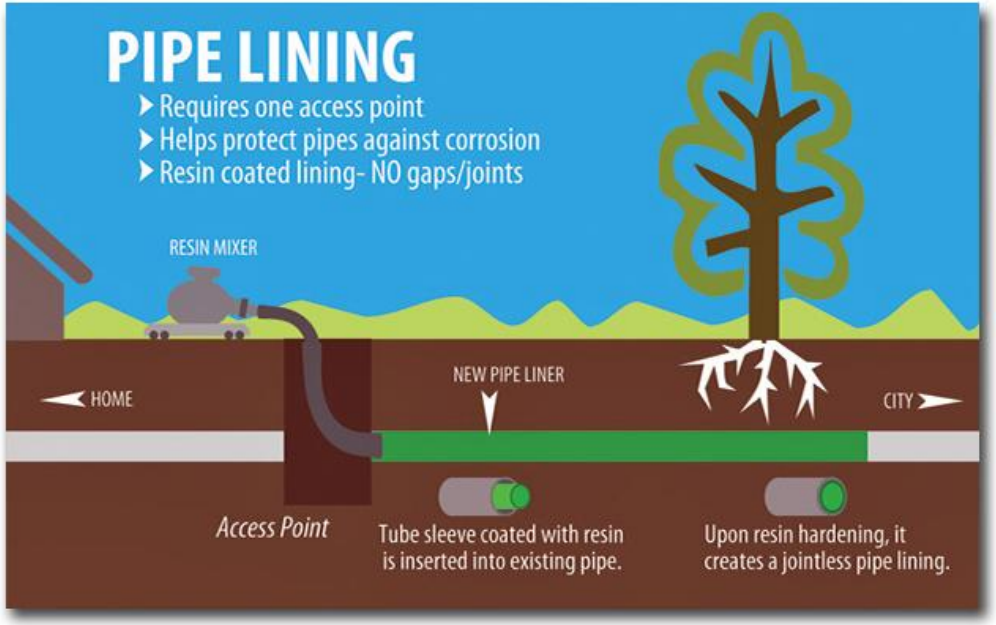
Combined sewers – maintenance

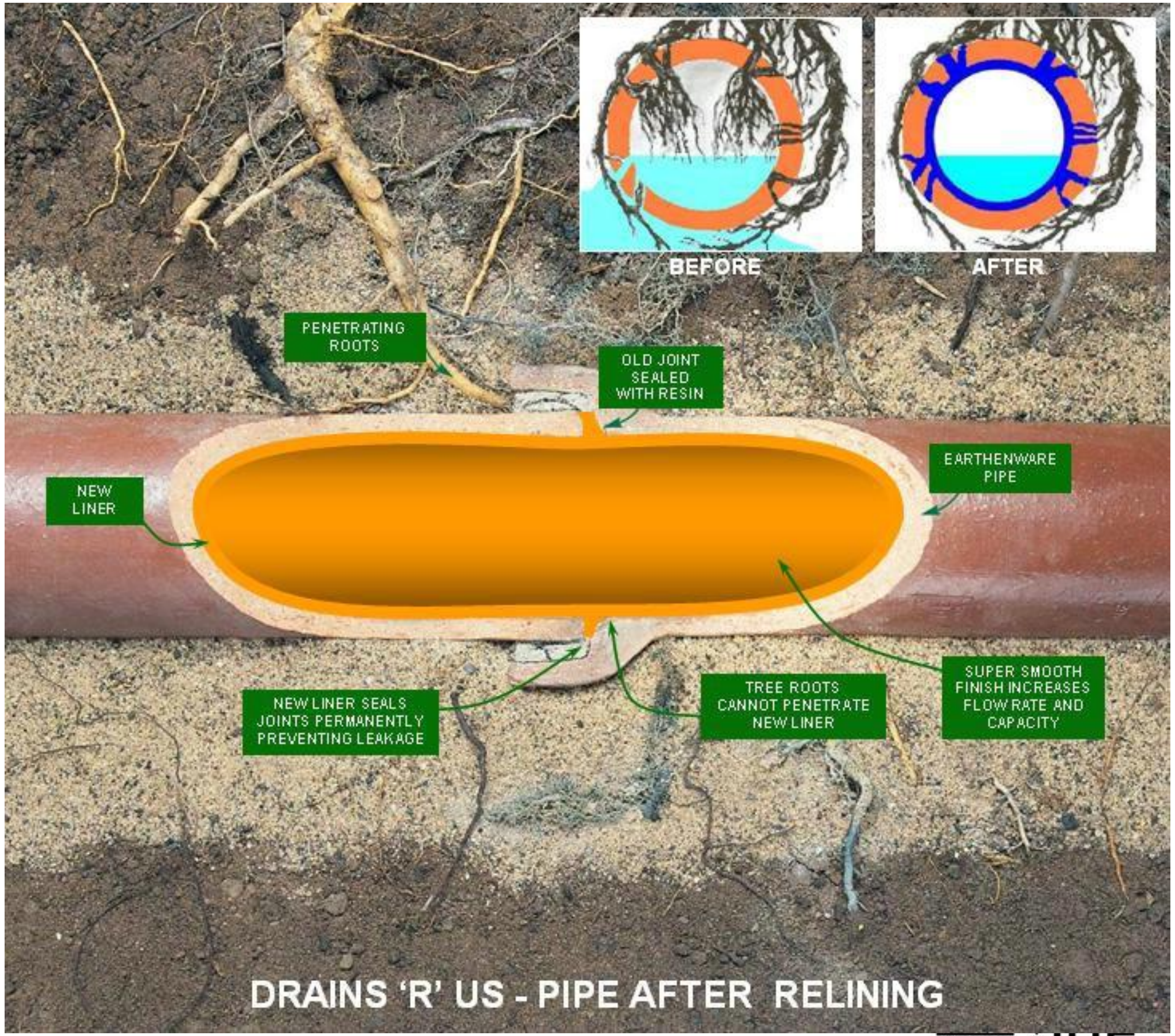
- Inspection
- Cleaning
- Root trimming
- Relining

Combined sewers – maintenance

- Inspection
- Cleaning
- Root trimming
- Relining

Epoxy resin

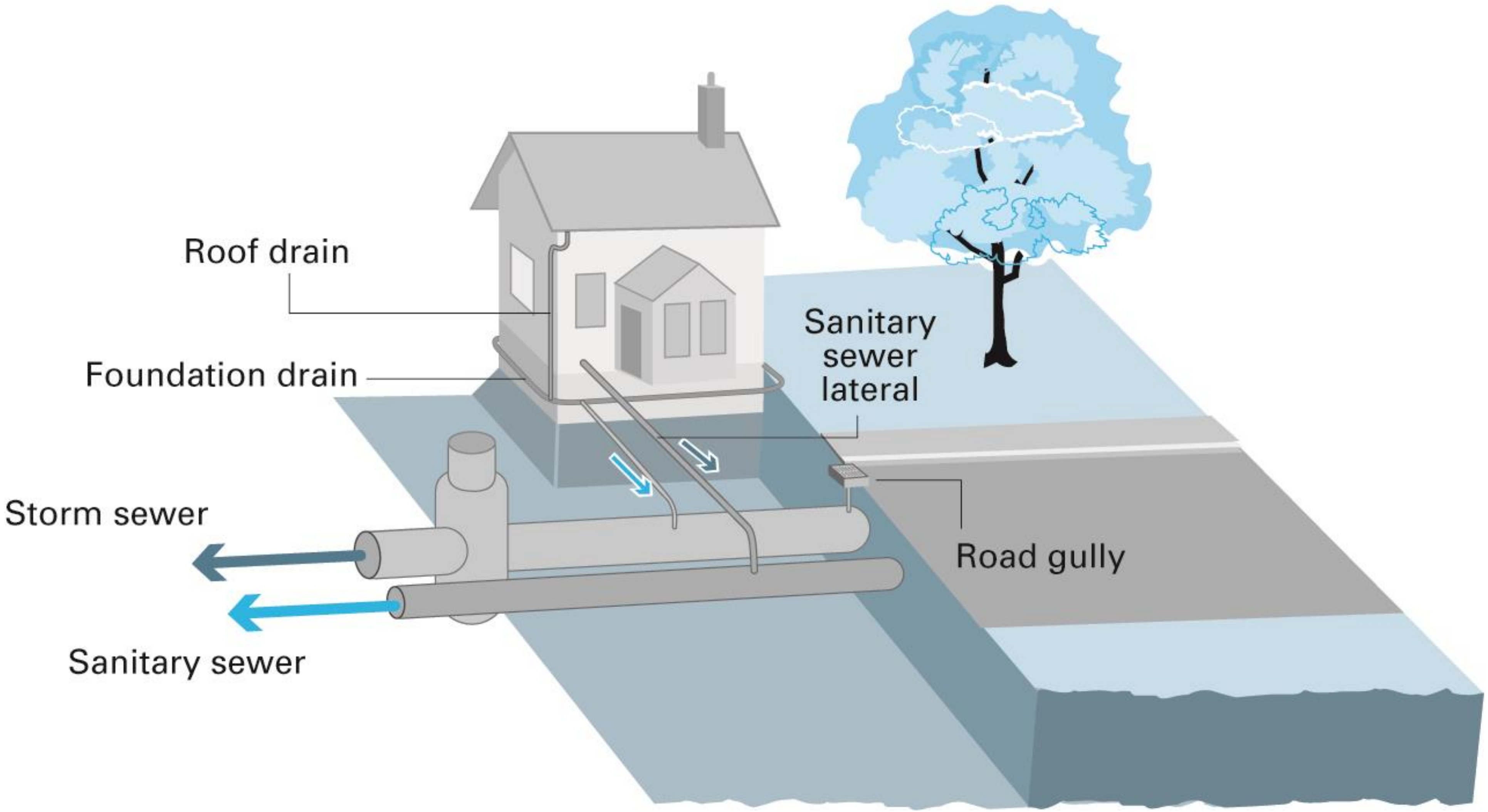




Combined sewers

Advantages	Disadvantages
Convenience (minimal intervention by users)	High capital costs
Low health risk	Need a reliable supply of piped water
No nuisance from smells, mosquitoes, or flies	Difficult to construct in high-density areas, difficult and costly to maintain
Stormwater and wastewater can be managed at the same time	Recycling of nutrients and energy becomes difficult
No problems related to discharging industrial wastewater	Requires skilled engineers and operators
Moderate operation and maintenance costs	Problems associated with blockages and breakdown of pumping equipment
	Adequate treatment and/or disposal required

Separate Sewers



Separate Sewers – cost and health aspects

- The construction costs can be higher than for the combined sewer system because separate networks are required
- The replacement of a combined with a separate system is very costly
- In a properly constructed separate sewer system the sewage is transported in a closed system directly to the treatment plant

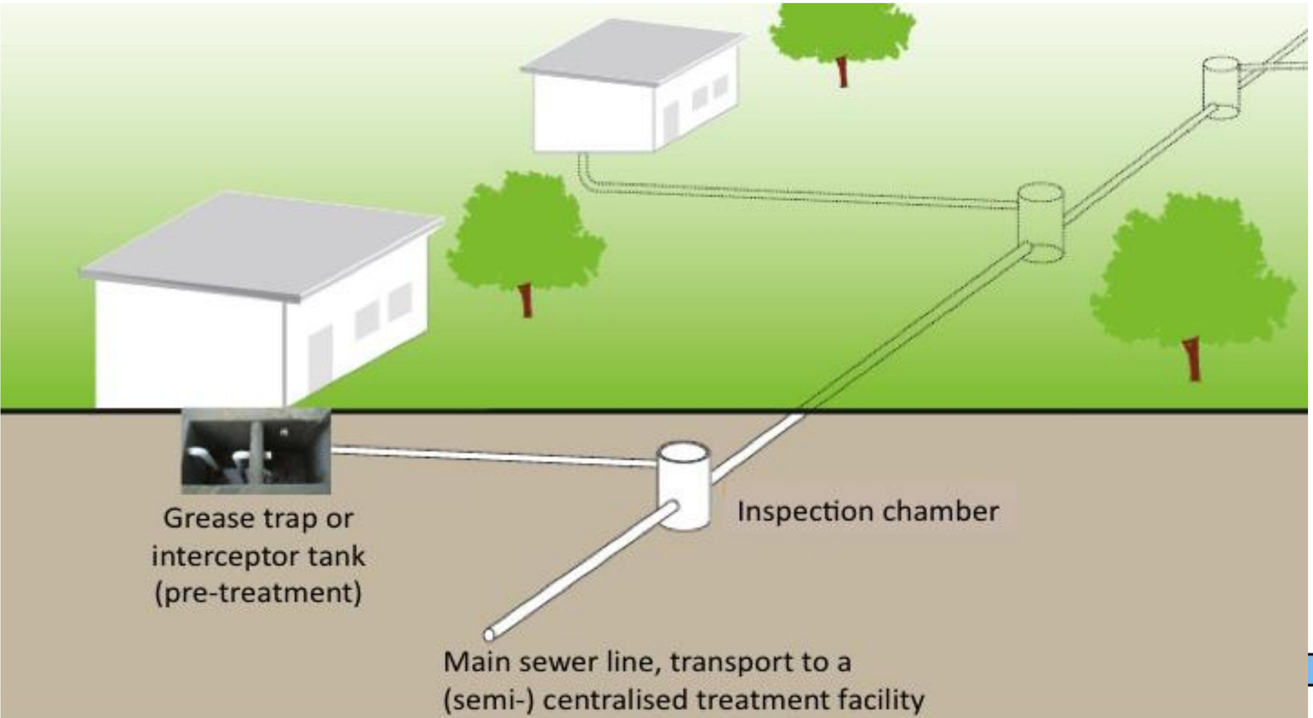
Separate sewer systems

Advantages	Disadvantages
Surface runoff, greywater and blackwater can be managed separately	Needs a reliable supply of piped water
Limited or no risk of sewage overflow	Difficult to construct in high-density areas, difficult and costly to maintain
Convenience (minimal intervention by users)	High capital costs, more expensive than combined sewer system
Low health risk	Requires skilled engineers and operators
No nuisance from smells, mosquitoes or flies	Need for pumping on flat ground
No problems related to discharging industrial wastewater	Problems associated with blockages and breakdown of pumping equipment
Moderate operation costs	Adequate treatment and/or disposal required for a large point source discharge
Surface run-off and rainwater can be reused (e.g. for landcaping or agriculture)	

Combined vs separate sewers?

Simplified and condominal sewers

- A sewer system that is constructed using smaller diameter pipes (e.g 100mm) laid at a shallower depth and at a flatter gradient than conventional sewers
- Flexible design associated with lower costs

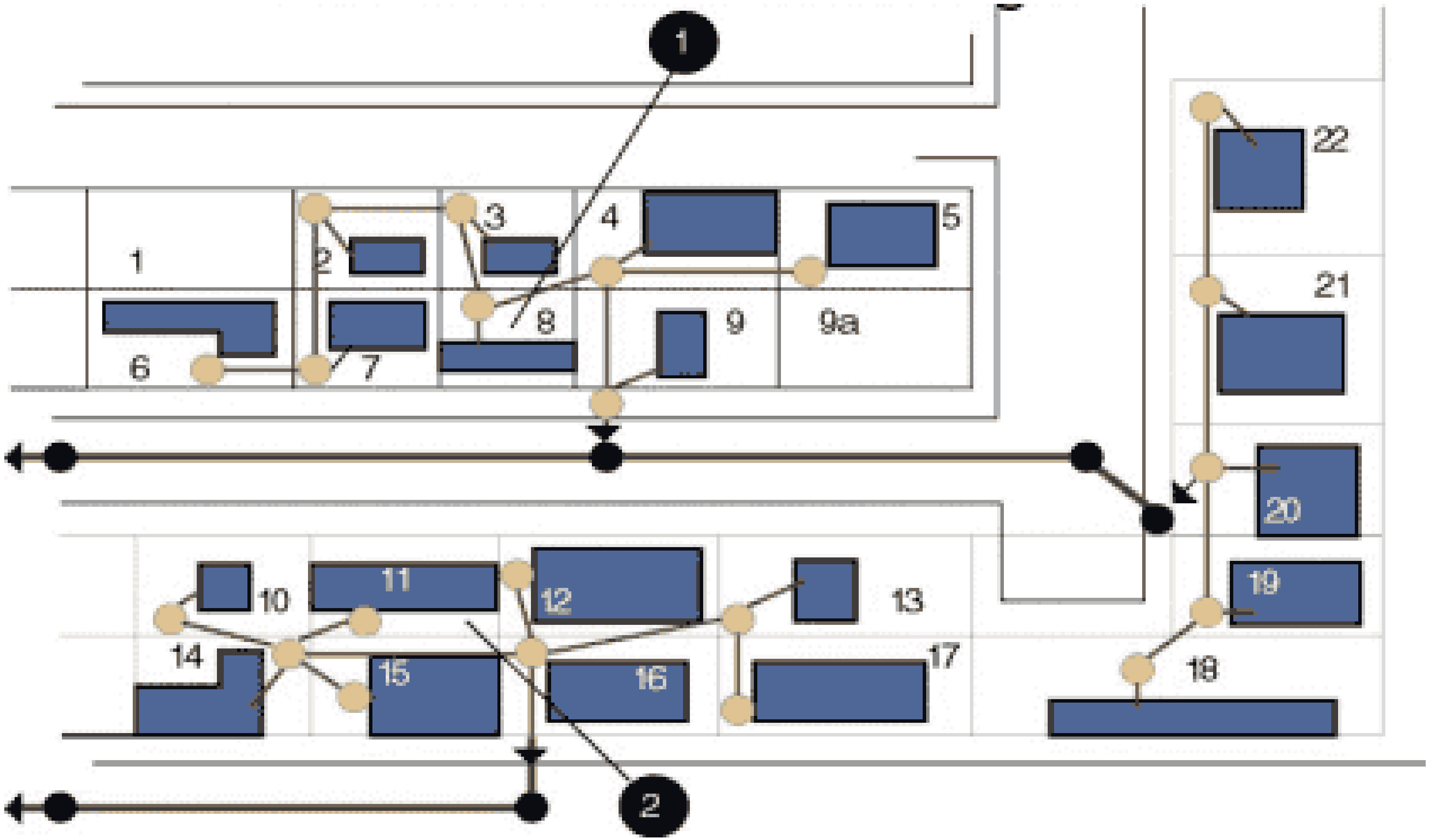


Source: STAUFFER (2012), adapted from TILLEY et al. (2008)

Simplified sewer – basic design principles

- Sewers are laid within the property boundaries and side walks, rather than beneath the central road
- Every household should have a grease trap or an other appropriate pre-treatment facility.
- Semi-centralised treatment facility or transfer/ discharge station.
- Stormwater drainage system is still required

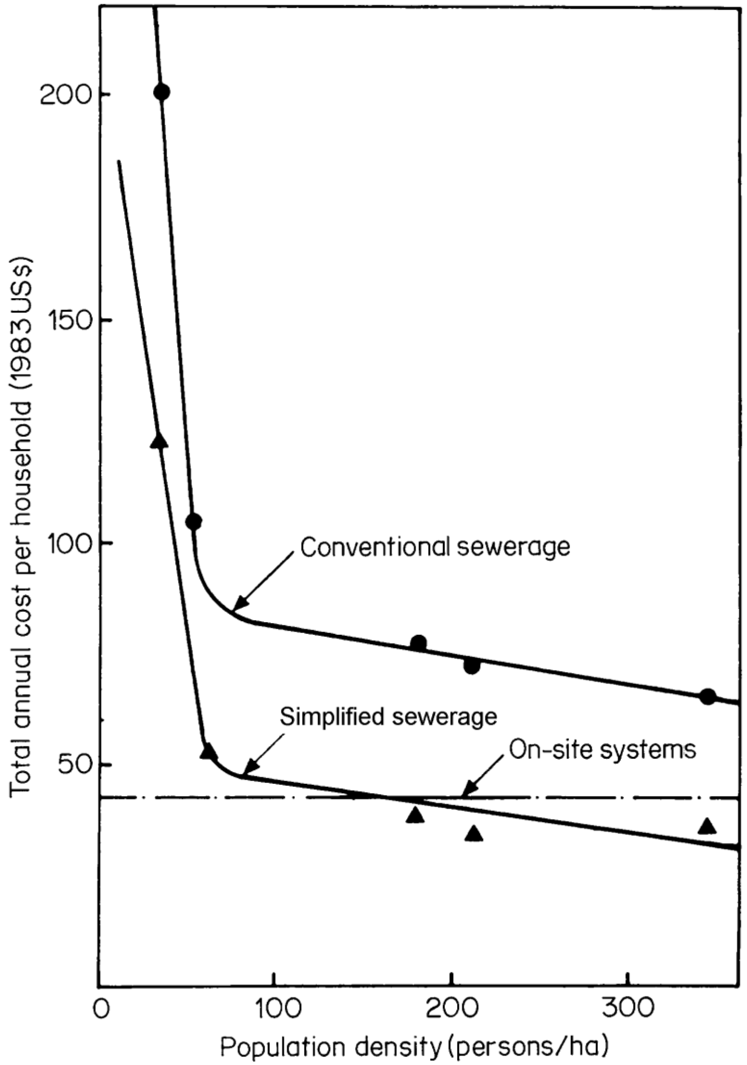
Simplified and Condominal Sewers



Simplified sewer – Applicability

- The costs of simplified sewerage systems are low (50 to 80% less expensive than conventional gravity sewerage), sometimes even lower than those of onsite sanitation
- This is because simplified sewerage uses flatter gradients, shallow excavation depths, small diameter pipes, and simple inspection units
- Where the ground is rocky or the groundwater is high
- They can be installed in almost all types of settlements and are especially appropriate for dense urban settlements

Simplified sewer – Costs



Simplified sewer – Operation and maintenance

- No solids should enter the system
- Blockages need to be removed and the system needs to be flushed periodically
- The pipeline system components, such as cleanouts or ventilation points should be regularly checked and maintained

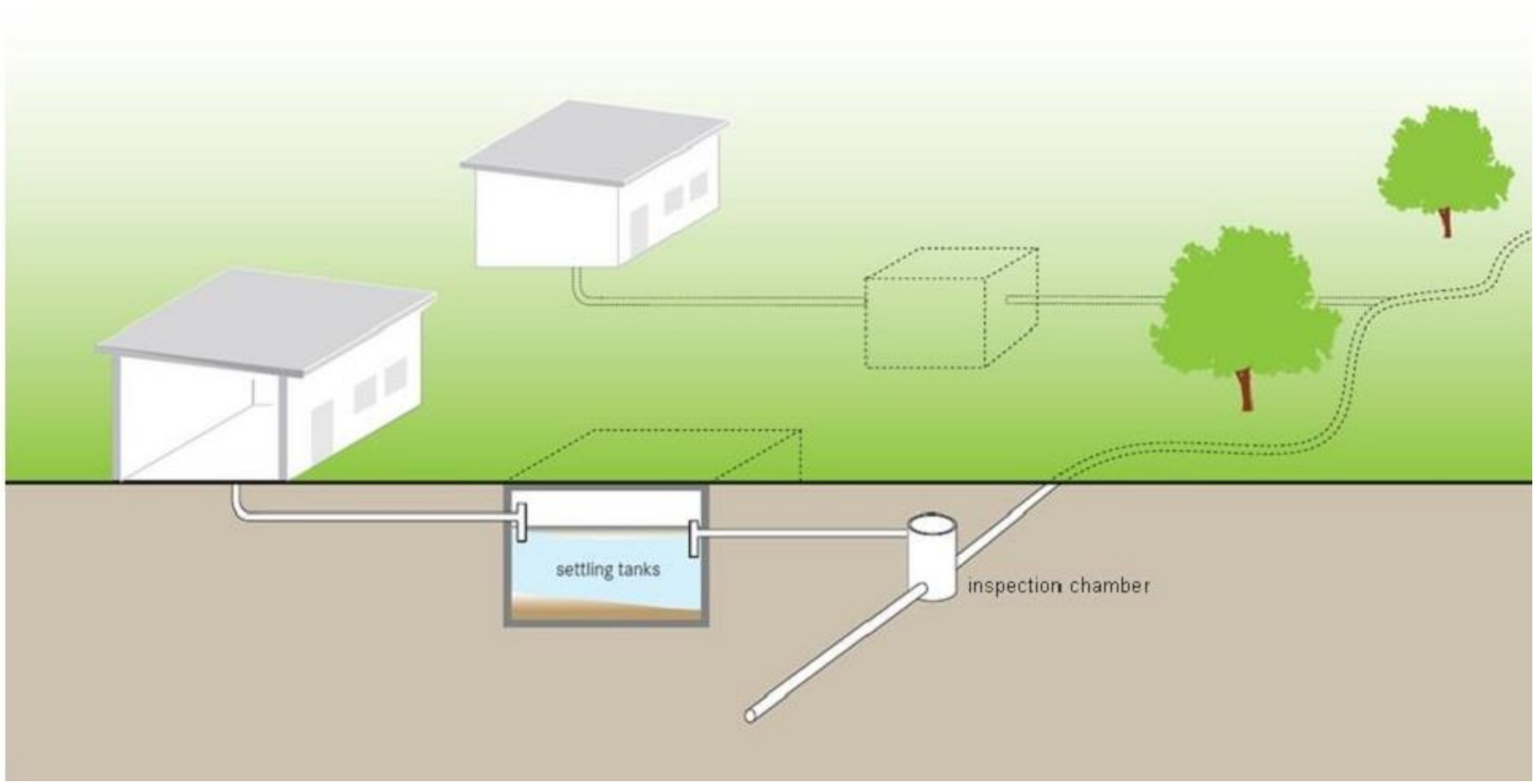
Simplified sewer systems

Advantages	Disadvantages
Can be built and repaired with locally available materials	Requires a large amount of water for flushing
Capital costs are between 50 and 80% less than conventional gravity sewers	Requires expert design and construction supervision
Operating costs are low	Requires frequent repairs and removal of blockages
Can be extended as a community changes and grows	Only suitable where there are interceptor tanks, septic tanks or other on-site pre-treatment systems

Solids-free sewers

- These are similar to conventional sewer systems, except that the wastewater is pre-settled and solids removed (in a settling or septic tank) before entering the system
- As solids are removed, sewer diameter can be much smaller and they can be constructed using less conservative design criteria (lower gradients, fewer pumps, shallower pipe depths, etc) resulting in significantly lower investment costs
- Due to the simplified design, solids-free sewers can be built at lower cost (20% to 50% less costs than conventional sewerage).

Solids-free sewers – design aspects



Solids-free sewers – design aspects

- A precondition is an efficient pre-treatment at the household level. The interceptors remove settleable particles that may clog the small pipes
- If well used and maintained
  - There is little risk of clogging; hence the sewers do not have to be self-cleansing and can be laid at shallow depths
  - Can have fewer inspection points (manholes)
  - Can follow the topography more closely and can even have adverse gradients (i.e. Negative slopes)

Solids-free sewers – operation and maintenance

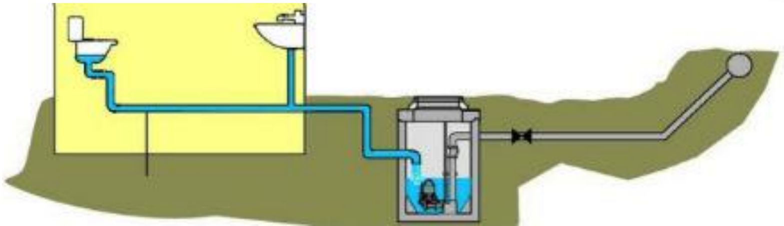
- The pre-settling units must be maintained and emptied regularly to ensure optimal performance
- The risk of pipe clogging is low if the sewers are well operated and maintained, however, some maintenance is required periodically
- Regardless of performance, the sewers should be flushed once a year

Solids-free sewers

Advantages	Disadvantages
Can be built and repaired with locally available materials	Requires repairs and removals of blockages more frequently than a conventional sewer
Low operating costs if well maintained	Requires expert design and construction supervision
Can be extended as a community changes and grows	Requires education and acceptance to be used correctly
Appropriate for densely populated areas with sensitive groundwater or no space for a soak pit of a leaching field	Effluent and sludge (from interceptors) requires secondary treatment and/or appropriate discharge

Pressurised Sewers

- Pressurised sewers use pumps instead of gravity to transport wastewater
- The primary effluent is delivered to the collection tank by gravity, where it is grinded (pressed) before being transported into the pressurised system by pumps
- The system can be built with only shallow trenches and relatively small-diameter pipes



Pressurised Sewers

- It is an effective solution where conventional systems are impractical such as in rocky, hilly or densely populated areas, or areas with a high groundwater table

Pressurised Sewers – working principle

- A pit containing a grinder and pump or a settling unit (septic tank) connected to a holding tank with a pump are installed close to the user
- When a certain level of effluent has been collected, it is pumped into the sewer, generating the pressure for transportation

Pressurised Sewers – cost consideration

- High capital costs, but still lower than gravity sewer systems
- The costs include the pumps, basins, controls, electrical services, and installation

Pressurised Sewers – operation and maintenance

- All system components should be regularly serviced
- Electricity needs to be available all the time
- The pumps should be checked regularly and the pipe connections should be controlled for leakages
- Frequency of operation and maintenance depend on wastewater volume



Pressurised sewers

Advantages	Disadvantages
Effective wastewater transportation at minimum depth, minimising excavation for piping system	Needs expert design
Independent from land topography	Needs a permanent energy source for the grinder pumps
Lower costs compared to a conventional gravity sewer	High capital costs
Requires little water only for transporting the excreta	Requires skilled engineers and operators

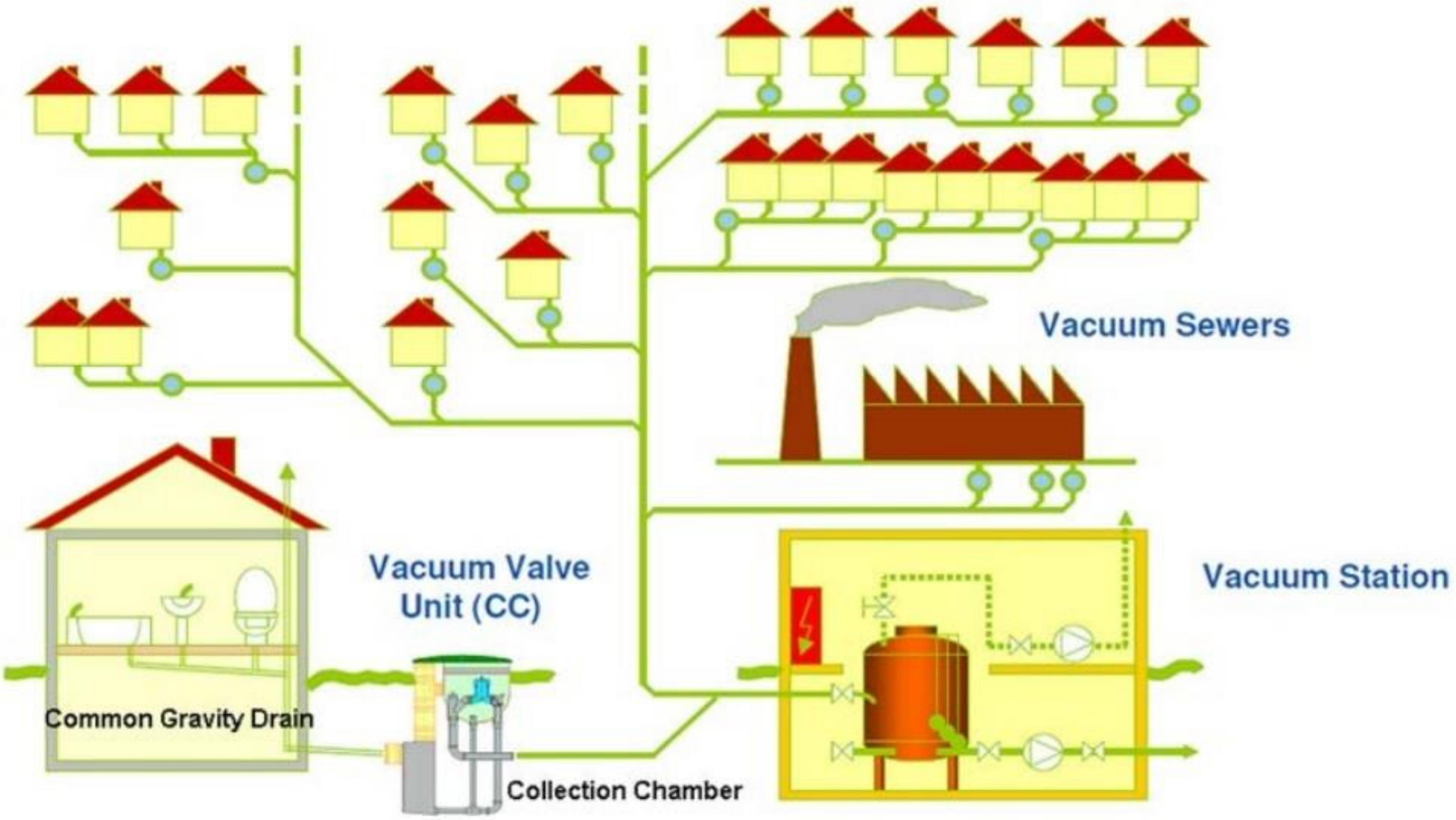
Vacuum sewers

- Vacuum sewer systems use a central vacuum source to convey sewage from individual households to a central collection station
- Vacuum sewers use differential air pressure (negative pressure) to move the sewage
- A central source of power to operate vacuum pumps is required to maintain vacuum (negative pressure) on the collection system

Vacuum sewers – working principle

- A gravity line carries wastewater down to the collection chamber
- As soon as the level reaches a defined height, the vacuum interface valve opens and the negative pressure sucks the wastewater into the vacuum sewer main
- When the collection tank at the end of the vacuum system fills to a predetermined level, sewage pumps transfer the contents to a treatment plant via a conventional or separate sewer system

Vacuum sewers



Vacuum sewers – cost considerations

- As it is a high-tech system, it is costly, but cheaper than conventional sewer system
- Piping costs are lower (smaller dimensions) and pipe installation can be cheaper because piping is independent from the topography and shallow
- No heavy machinery is necessary to excavate deep trenches
- Large amounts of dewatering can be avoided
- The constant energy requirement for the permanent vacuum generation, however, can increase the costs

Vacuum sewers – Operation and maintenance

- The system needs instructed workers for maintenance and operation works
- Pressure in the vacuum sewer system should be tested from time to time
- The risk of clogging is low and there is almost no cleaning/emptying work

Vacuum sewers – applicability

- Areas where a traditional collection is too costly or not feasible
- Flat topography: gravity systems demand installation at great depths to maintain adequate flow
- Areas where rock layers or a high groundwater table make deep excavation difficult

Vacuum sewers

Advantages	Disadvantages
Requires less water to transport the excreta	Needs expert design
Considerable savings in construction costs, and much shorter construction period	Needs energy to create the permanent vacuum
Pipelines laid in shallow and narrow trenches. Small diameter pipelines, flexible pipeline construction	High capital costs
Sewers and water mains can be laid in a common trench	Recycling of nutrients and energy becomes difficult
Closed systems with no leakage or smell	Requires skilled engineers and operators
No manholes along the vacuum sewers	
One central vacuum station can replace several pumping stations	

Overflows

Overflows – What is the problem here?

… and here?

Lisbon Harbour, Portugal - Summer 1999

Open channels and drains

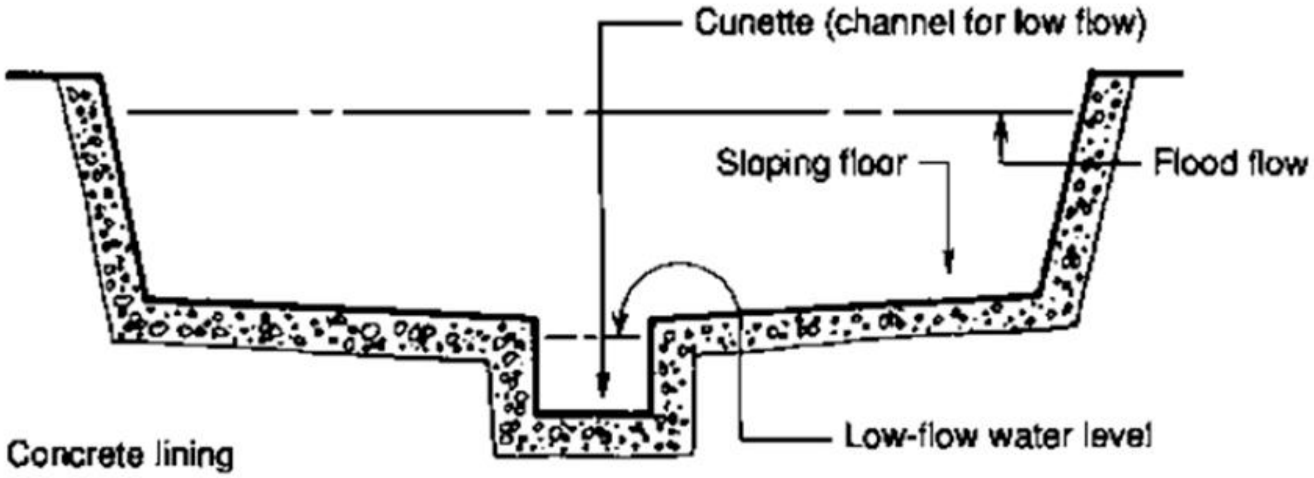
- An open channel is a conveyance in which water flows with a free surface
- Although closed conduits such as culverts and storm drains are open channels when flowing partially full, the term is generally applied to natural and improved watercourses, gutters, ditches, and channels

Open channels and drains – design principles

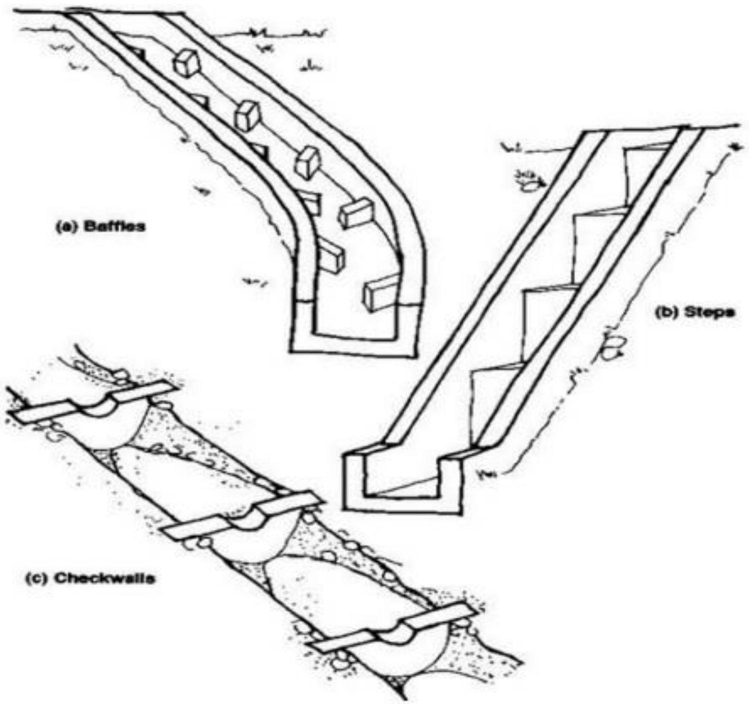
- An open channel or drain system generally consists of a secondary drainage system, with a network of small drains attached
- These small drains bring the water to a primary drainage system, composed of main drains (also called interceptor drains), which serve large areas
- The main drains are generally connected with natural drainage channels such as rivers or streams

Open channels and drains – design principles

- On steep terrain, erosion could affect the cross section
- In flat low-lying areas, the limited slope may result in channel with a composite channel



Open channels and drains



Baffles, steps and check walls to retard flow in steep terrains

Open channels and drains – cost considerations

- Less expensive compared to underground sewer systems
- The costs depend on local condition
  - In very steep terrain – extra construction to slow down the flow velocity
  - In very flat areas or areas with high ground water tables, wide excavations could raise the costs

Open channels and drains – Applicability

- Can be constructed in almost all types of settlements (urban or rural), but enough land area is required to build a reasonable construction
- Even though they offer simple solutions for stormwater drainage, they bear many risks for public health and the environment due to the risk of illegal discharge of wastewater and solid waste

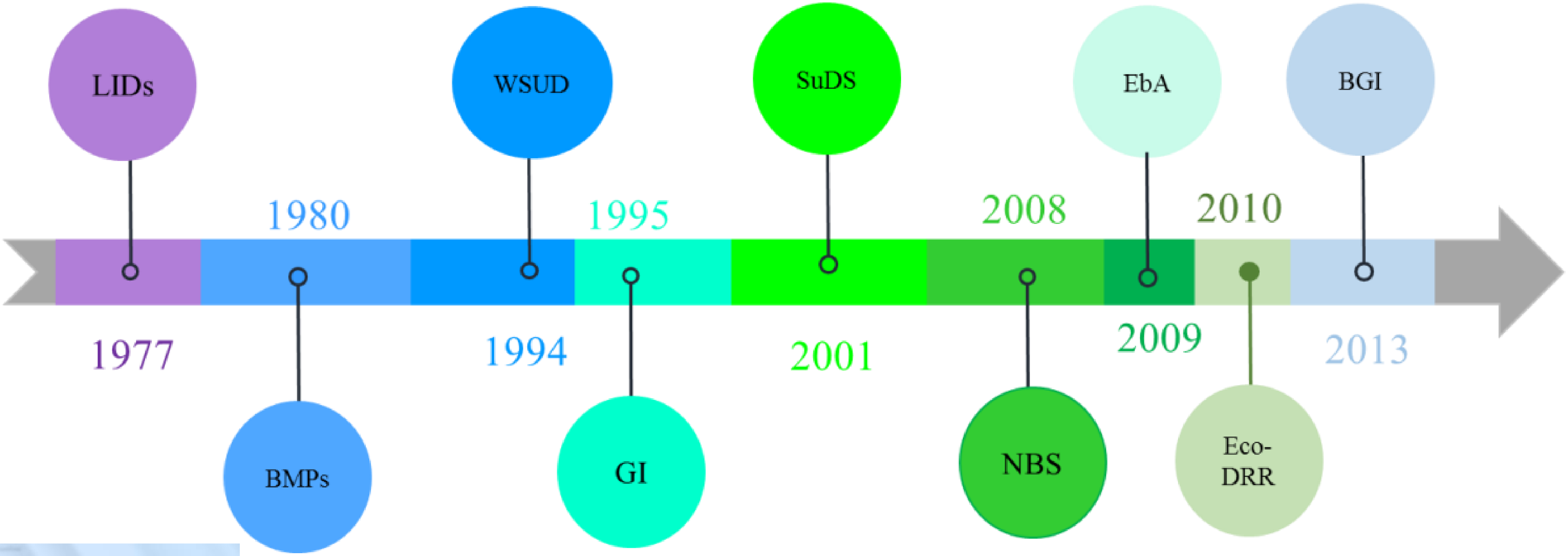
Open channles and drains

Advantages	Disadvantages
Less expensive	High health risk due to illegal discharge of wastewaters and solid waste
Simple to construct	Breeding ground for insects and pests
Construction materials are often locally available	Regular cleaning service required to remove solids and blockages which usually causes spill-over and flooding

Green infrastructure (or nature-based) solutions

- The GI approach refers to the natural or semi-natural systems that provide services for water resources management with equivalent or similar benefits to conventional (built) “grey” water infrastructure.
- Green Infrastructure solutions for water management are also at the heart of Ecosystem-based Adaptation – defined as [using] “…” (UNEP 2010). ***biodiversity and ecosystem services as part of an overall adaptation strategy to help people & communities adapt to the negative effects of climate change at local, national, regional and global levels***

Terminology



[(Ruangpan et al, 2019)](https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2019-128/)
https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2019-128/

Green infrastructure solutions

Green Infrastructure solutions are based on the utilization of ecosystem services

- Provisioning Services: ecosystem services that describe the material or energy outputs from ecosystems. They include food, water and other resources.
- Regulating Services: services that ecosystems provide by acting as regulators e.g. by regulating the quality of water and soil or by providing flood and disease control.
- Cultural Services: nonmaterial benefits that people obtain from ecosystems though spiritual, recreational and aesthetic experiences.
- Habitat or Supporting Services: services needed for the production of all other services. They differ from provisioning, regulating and cultural services in that their benefits to people are indirect.

Green/Blue Infrastructure ***small/local/urban scale***

Green/Blue Infrastructure
large/rural/watershed scale





Green infrastructure solutions - examples

- Larger scale – e.g., river basin
- Local scale – e.g., city, urban

Green infrastructure solutions

Reforestation, Afforestation and Forest Conservation

Reforestation and afforestation refer to activities where trees are established on lands with no forest cover.

Green infrastructure solutions

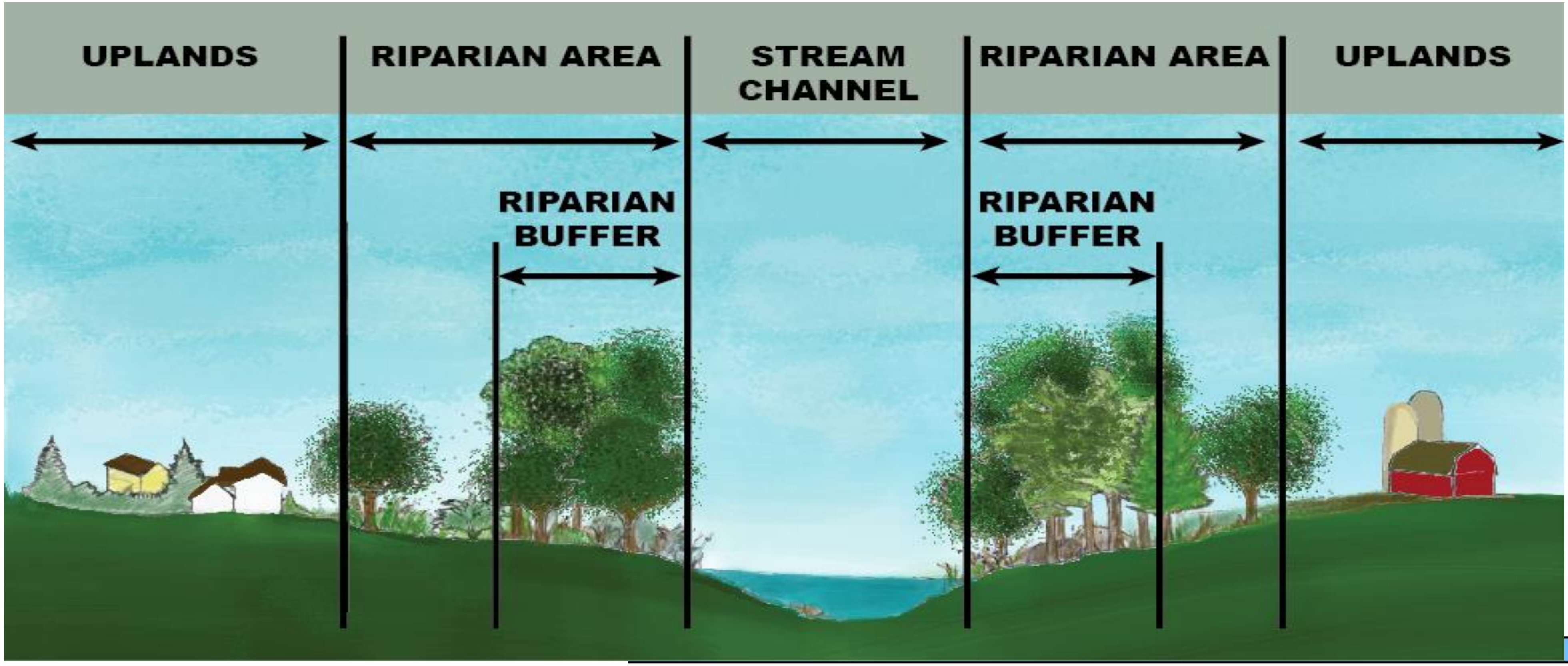
Reforestation, Afforestation and Forest Conservation

Water Management Benefits	Co-benefits
Riverine flood control	Carbon sequestration
Water supply regulation (including drought mitigation)	Biodiversity benefits (incl. pollination)
Water purification and biological control	Improved air quality
Water temperature control	Climate regulation
Erosion control (reduced risks of landslides, mudflows and avalanches)	Recreational, tourism and alternative livelihood possibilities

Green infrastructure solutions

Riparian Buffers

Riparian buffers are vegetated, often forested, areas ("strips") adjacent to streams, rivers, lakes and other waterways protecting aquatic environments from the impacts of surrounding land use.



Green infrastructure solutions

Riparian Buffers

Water Management Benefits	Co-benefits
Riverine flood control	Biodiversity benefits (incl. pollination)
Water purification and biological control	Recreational, aesthetic value
Water temperature control	
Erosion control (reduced risks of landslides, mudflows and avalanches)	

Green infrastructure solutions

Wetland Restoration/Conservation

Wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres.

Green infrastructure solutions

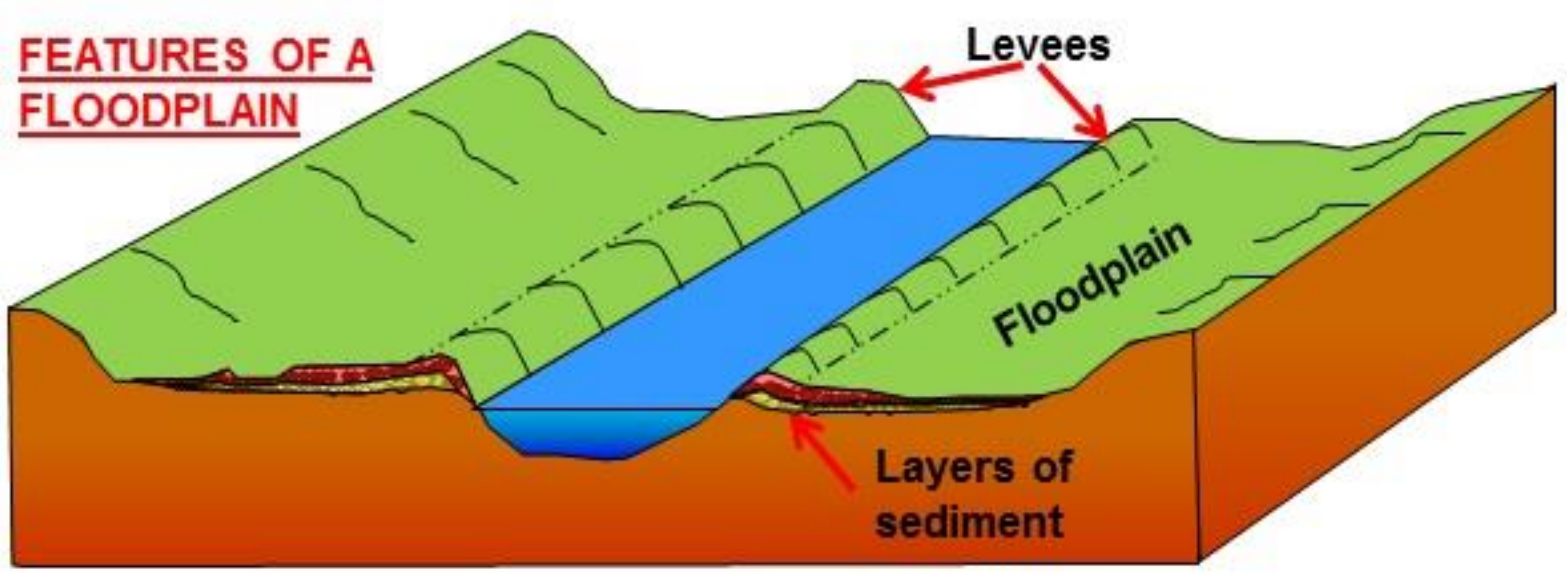
Wetland Restoration/Conservation

Water Management Benefits	Co-benefits
Water supply regulation (including drought mitigation)	Biodiversity benefits (incl. pollination)
Water purification and biological control	Recreational, aesthetic value
Water temperature control	Livelihood income possibilities
Flood mitigation	Climate change adaptation and mitigation (carbon storage and sequestration)

Green infrastructure solutions

Reconnecting Rivers to Floodplains (levee setbacks or removal)

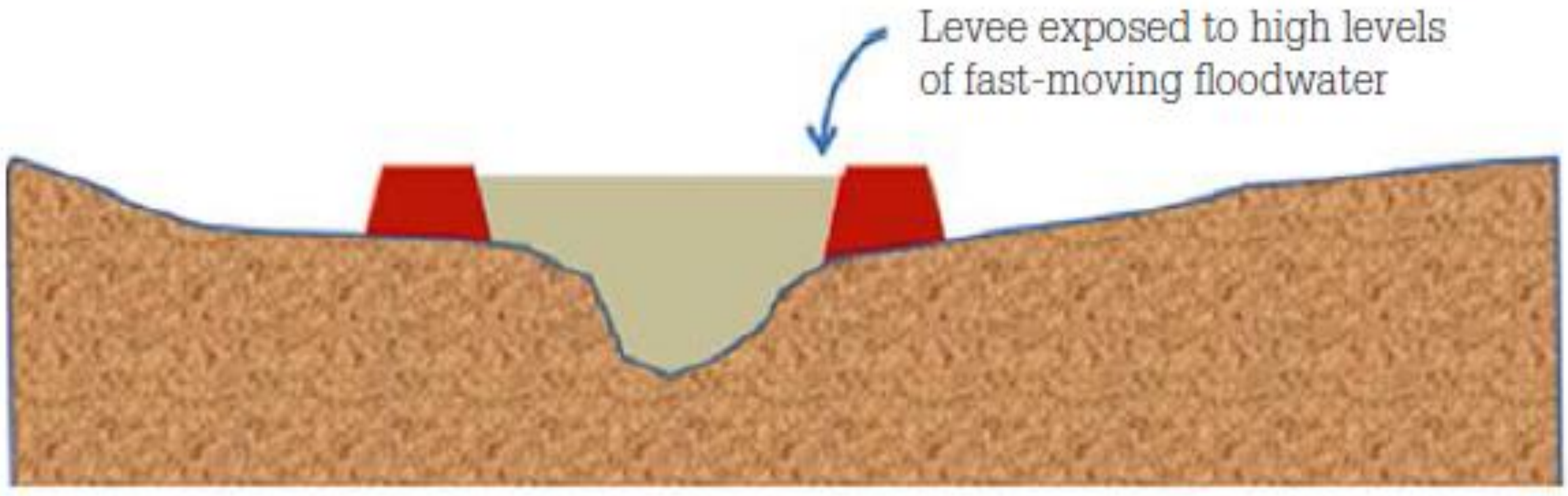
- Along many major rivers, levees have been constructed close to the edge of the river channel, which maximizes the amount of land protected by a levee.
- By placing levees close to the channel, rivers become more effective conduits for drainage. It can also maximize the use of surrounding lands, even in times of high water levels.



Green infrastructure solutions

Reconnecting Rivers to Floodplains (levee setbacks or removal)

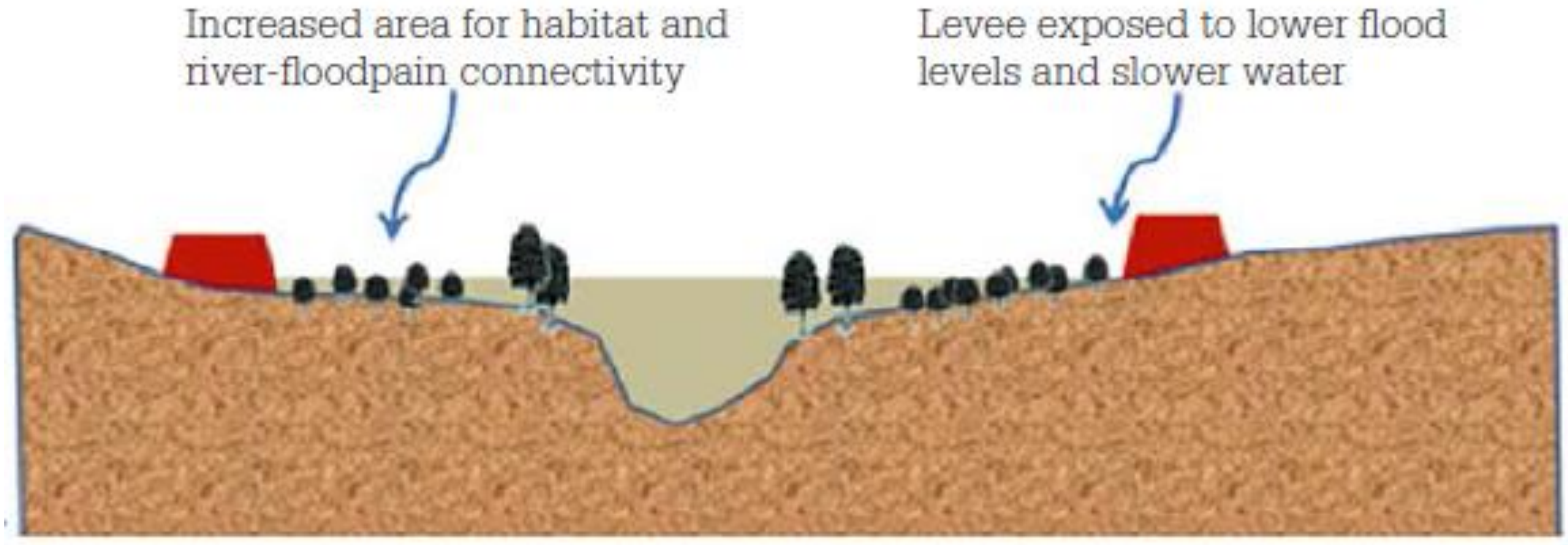
- However, levees close to the channel can create a set of problems and challenges. Because they greatly narrow the area available to transport floods, they do work to rapidly flush floodwaters and sediments through the system – but this means that the levees are exposed to high-velocity water along their “wet” side. This can result in erosion and high maintenance costs.



Green infrastructure solutions

Reconnecting Rivers to Floodplains (levee setbacks or removal)

- Levees close to a river also dramatically restrict the area of floodplain that benefits from periodic connections with the river and constricts the ability of the river to meander and create new river floodplain habitats.
- Moving levees back away from the channel - often called "setback levees" - can alleviate these problems



Green infrastructure solutions

Reconnecting Rivers to Floodplains (levee setbacks or removal)

Water Management Benefits	Co-benefits
Water supply regulation (including drought mitigation)	Biodiversity benefits (incl. pollination)
Water purification and biological control	Recreational, aesthetic value
Water temperature control	Livelihood income possibilities
Flood mitigation	Climate change adaptation and mitigation (carbon storage and sequestration)
Erosion control	Reduced water treatment costs

Green infrastructure solutions

Flood Bypasses

- A flood bypass is a region of land or a large man-made structure that is designed to convey excess flood waters from a river or stream in order to reduce the risk of flooding on the natural river near a key point of interest, such as a city.
- Flood bypasses are typically used only during major floods and act in a similar nature to a detention basin.

Green infrastructure solutions

Flood Bypasses

Water Management Benefits	Co-benefits
Riverine flood control	Biodiversity benefits
Groundwater recharge	Recreational, aesthetic value
Water temperature control	Livelihood income possibilities (hunting, fishing, farming).

Green infrastructure solutions

Swales

A swale is a low tract of land, which can be an artificial or a natural.

Swales are designed to slow and capture runoff by spreading it horizontally across the landscape.

Green infrastructure solutions

Rain gardens

A rain garden is a planted depression that allows stormwater runoff to be soaked into the ground. They require specific soils and conditions.

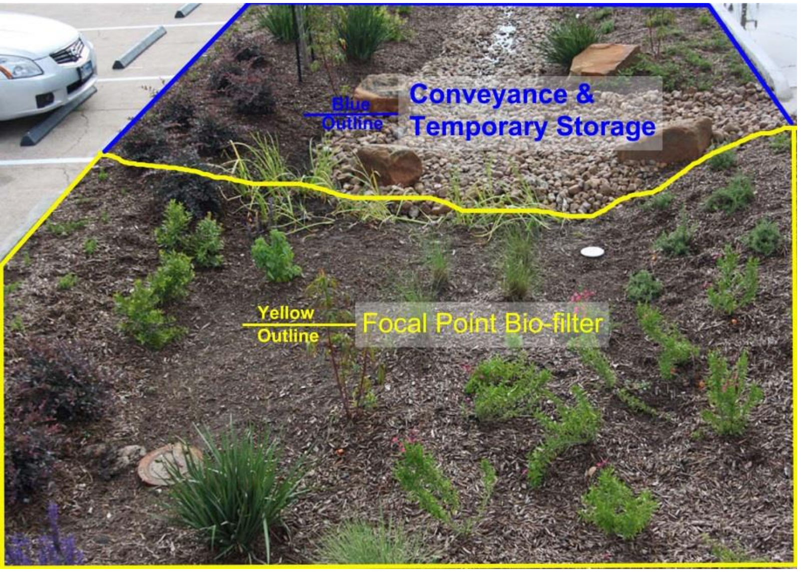
They can improve the quality of stormwater runoff which may be used for other purposes.

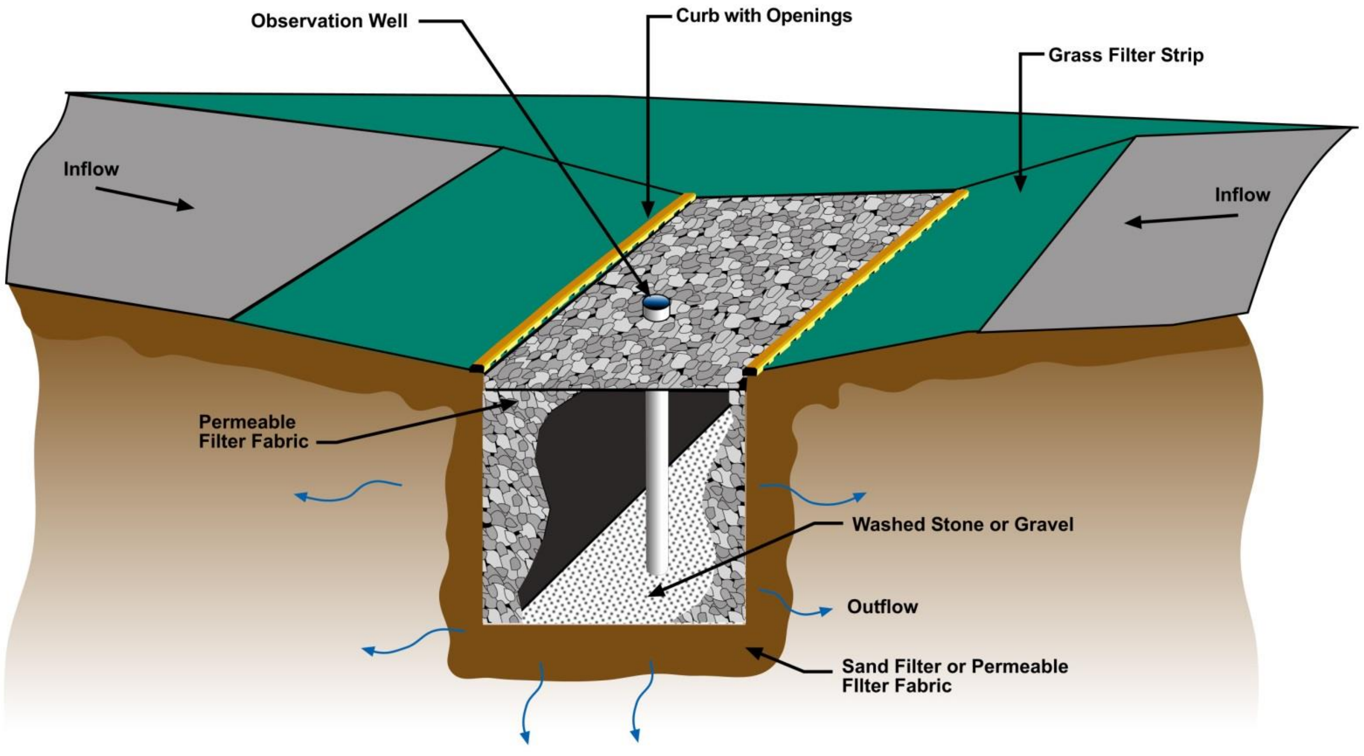
Green infrastructure solutions

Infiltration/biofiltration trenches

Infiltration trenches are shallow trenches with rubble/stone that create temporary subsurface storage of stormwater runoff. Infiltration trenches allow water to exfiltrate into the surrounding soils from the bottom and sides of the trench.

Biofiltration is a pollution control technique using a bioreactor containing living material to capture and biologically degrade pollutants.





INFILTRATION TRENCH

Green infrastructure solutions

Green walls

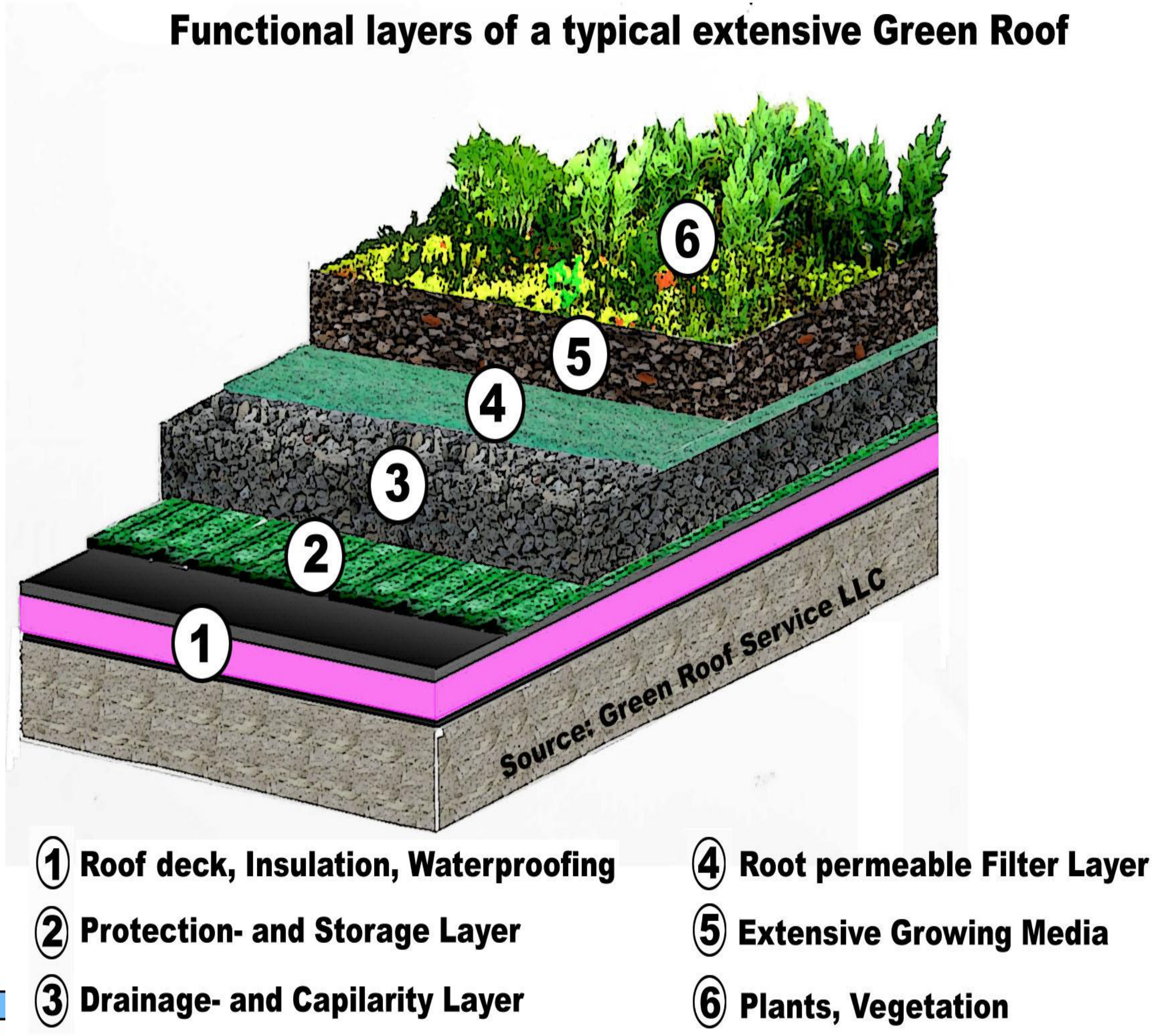
A green wall is a wall partially or completely covered with greenery that includes a growing medium, such as soil.

Green walls are also known as living walls or vertical gardens. They are good for microclimate and temperature/energy regulation.

Green infrastructure solutions

Green Roofs

Green roofs (also referred to as eco-roofs) are building roofs that are fully or partially covered with vegetation.



Green infrastructure solutions

Green Roofs

Water Management Benefits	Co-benefits
Flood mitigation (urban storm water control)	Biodiversity benefits
	Aesthetic value
	Improved air quality
	Reduced noise pollution
	Carbon sequestration
	Energy savings (reduced cooling and heating needs)
	Reduced urban heat island effect

Green infrastructure solutions

Green Spaces

Green spaces refer to areas of land that are partly or completely covered with grass, trees or other types of vegetation, creating basis for **bio-retention and infiltration-related practices**. Most of these are relevant to an urban context, as they help to deal with stormwater runoff in the presence of large areas of impervious surfaces

Green infrastructure solutions

Green Spaces

Water Management Benefits	Co-benefits
Flood mitigation (urban storm water runoff control)	Biodiversity benefits
Water purification	Aesthetic value
Water supply regulation (improved groundwater recharge)	Improved air quality
Temperature control (shading of water ways)	Energy savings for water treatment
	Carbon sequestration
	Reduced urban heat island effect

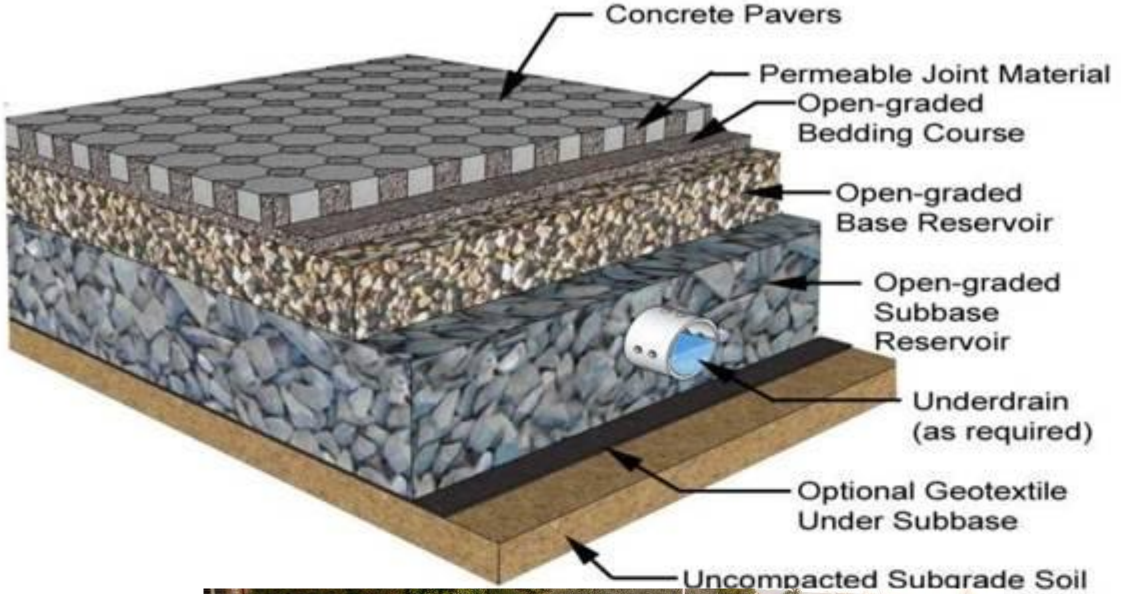
Green infrastructure solutions

Permeable Pavements

Conventional pavement alternatives such as asphalt and concrete are impervious surfaces, preventing any runoff infiltration.

Permeable pavement is made of materials that allow for the water to infiltrate, be filtered and recharge groundwater.

Types of permeable pavement materials include pervious concrete and asphalt, permeable interlocking concrete pavers (PICPs), concrete grid pavers, and plastic reinforced grass pavement



Green infrastructure solutions

Permeable Pavements

Water Management Benefits	Co-benefits
Flood mitigation (urban storm water runoff control)	Improved air quality
Water purification	Reduced urban heat island effect
Water supply regulation (improved groundwater recharge)	Reduced noise pollution

Green infrastructure solutions

Rainwater Harvesting

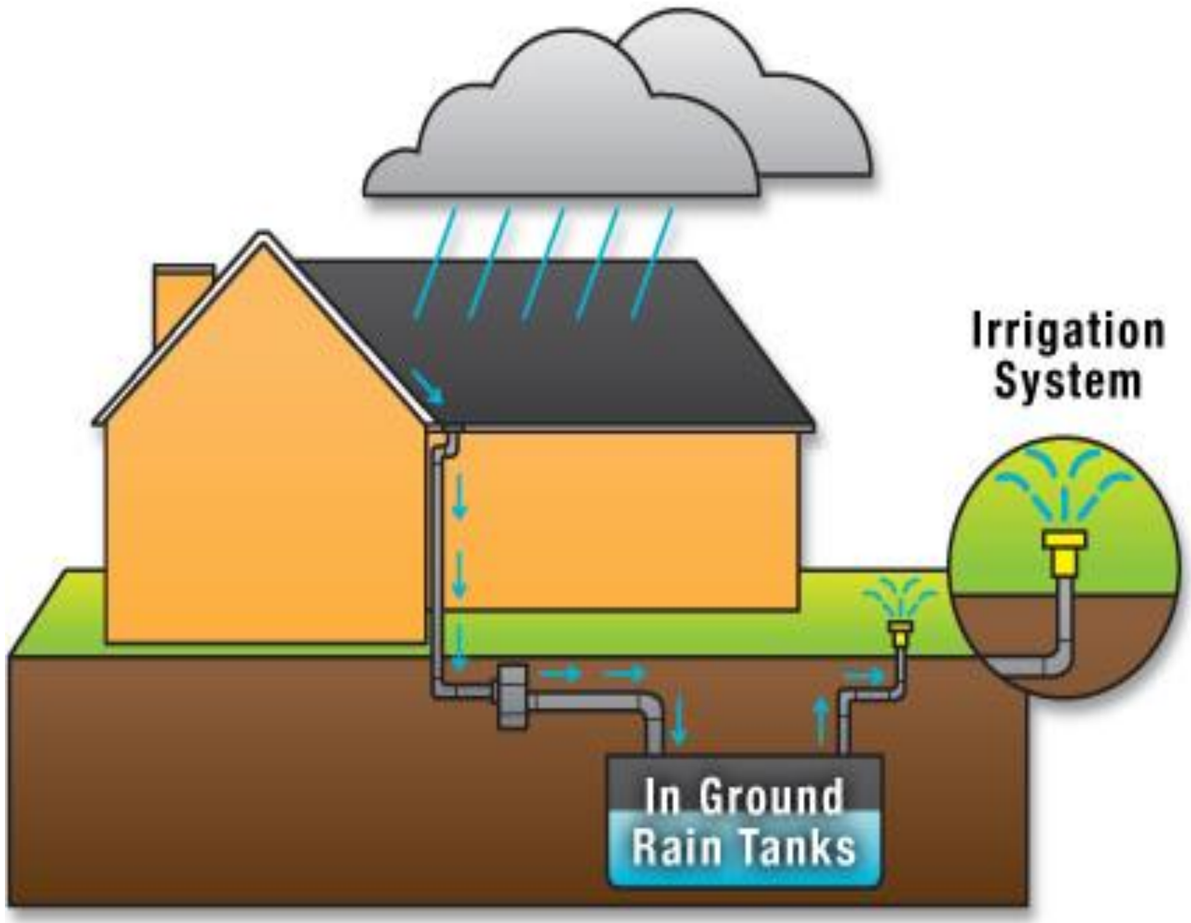
Rainwater harvesting refers to redirection of rainwater and stormwater runoff, and storage for productive use (agriculture, drinking water and more). Harvesting techniques can be divided in two main types:

In situ: In situ rainwater harvesting rainfall is trapped and stored in the desired location (primarily to ensure water for crops and other vegetation). This method ensures that rainwater remains where it falls with little distance between capture and usage areas. In in situ water harvesting, soil serves as the storage medium, with landscape serving as the collection and storage area.

Green infrastructure solutions

Rainwater Harvesting

<u>Ex situ</u>: Ex situ water harvesting uses systems where rainwater is captured in areas external to the final water storage. Capture areas in this case include natural soil surfaces or rooftops, roads and pavements in urban areas. Water is stored in natural or artificial reservoirs, with little or no infiltration capacity.



Green infrastructure solutions

Rainwater Harvesting

Water Management Benefits	Co-benefits
Water supply regulation (water storage and improved groundwater recharge)	Reduced costs of water conveyance and treatment, energy savings
Flood mitigation (reduced storm water runoff)	Climate change adaptation, increased resilience
Water purification (increased infiltration)	Maintained crop productivity, soil conservation
	Cultural value, preservation of traditional knowledge

Green infrastructure solutions

Protecting/restoring mangroves, marshes and dunes

Mangroves are trees and shrubs that are found in intertidal ecosystems where fine sediments accumulate and freezing is rare.

They inhabit extreme environments, including those with high salinity, high temperature, and extreme tides and muddy organic sediments devoid of oxygen

Green infrastructure solutions

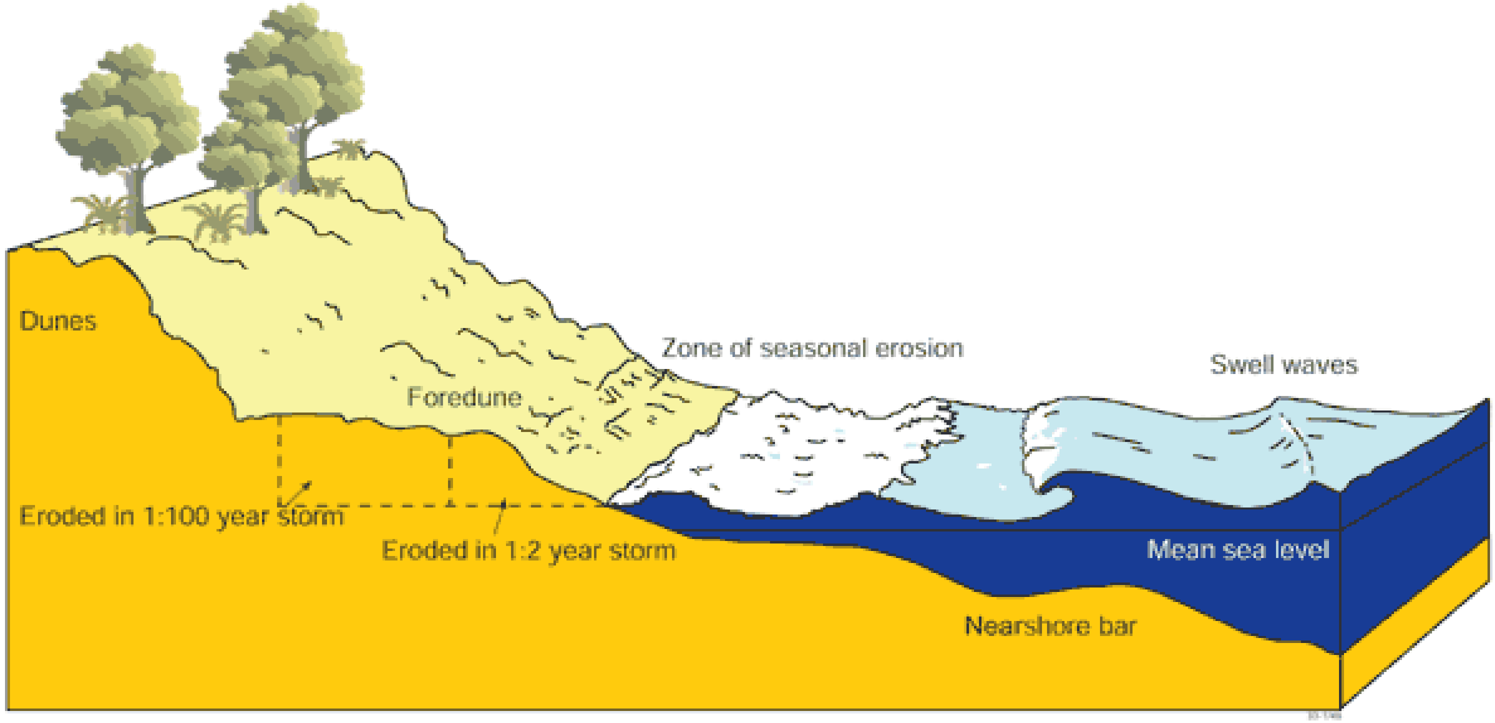
Protecting/restoring mangroves, marshes and dunes

Salt marshes are saline wetlands that are flooded and drained by salt water brought in by the tides.

Green infrastructure solutions

Protecting/restoring mangroves, marshes and dunes

Coastal sand dunes are naturally occurring wind formed sand deposits representing a store of sediment in the zone just landward of normal high tides, functioning as a natural defense barrier between the sea and the land.



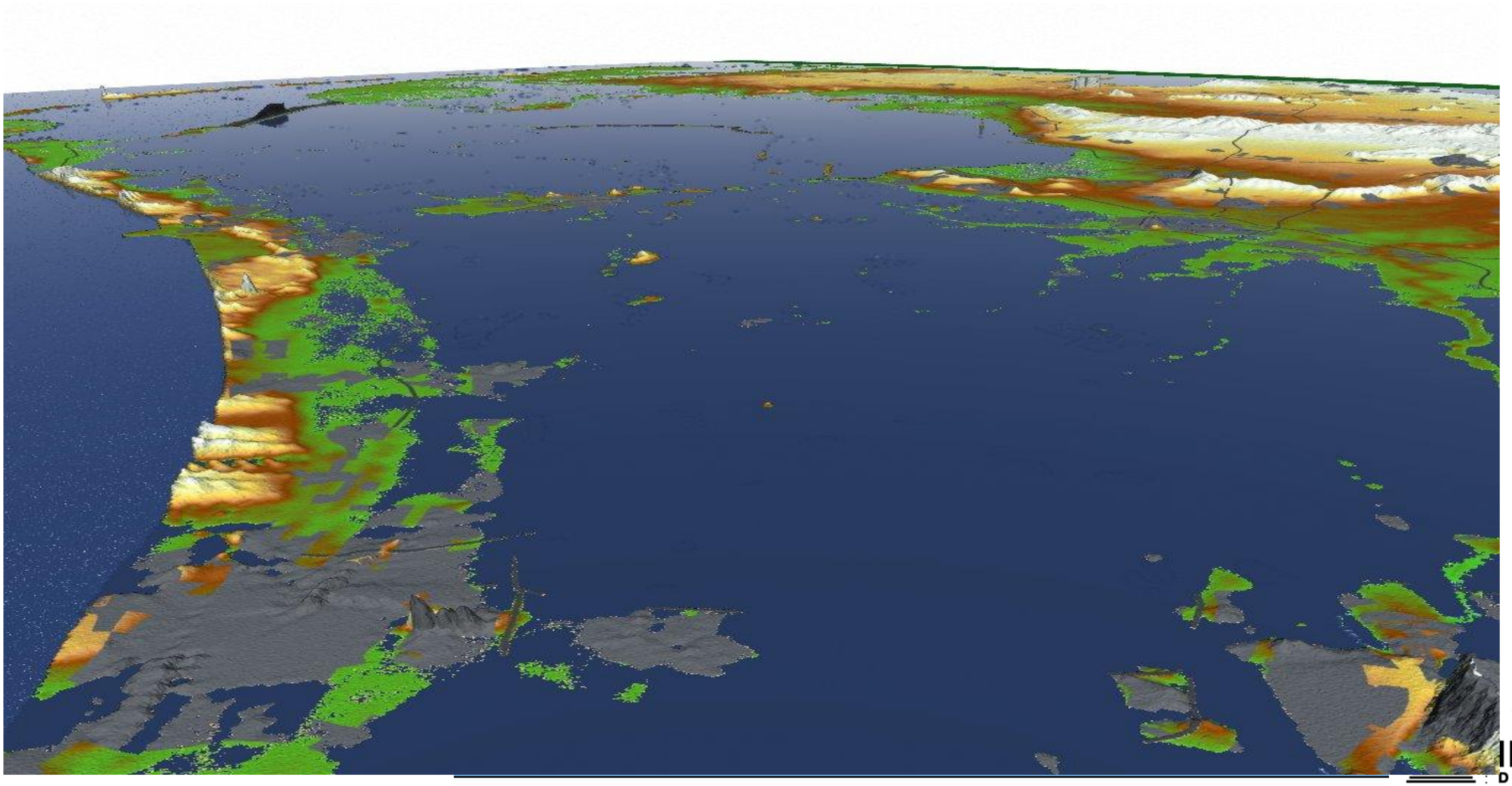
Green infrastructure solutions

Protecting/restoring mangroves, marshes and dunes

Water Management Benefits	Co-benefits
Coastal flood/storm protection	Biodiversity benefits (habitats preservation, breeding and nursery for birds, fish, shellfish and mammals)
Shoreline stabilization, erosion and sediment control	Climate change mitigation and adaptation (carbon storage, storm protection)
Reduced saltwater intrusion	Income opportunities (fisheries, raw materials, tourism)
	Recreational, aesthetic value

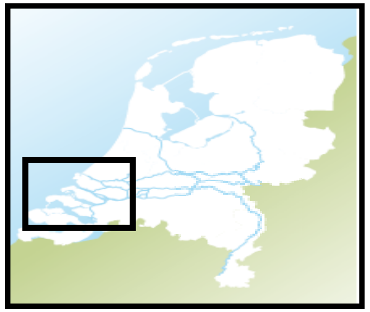
Dutch Case – “Room for the River Programme”

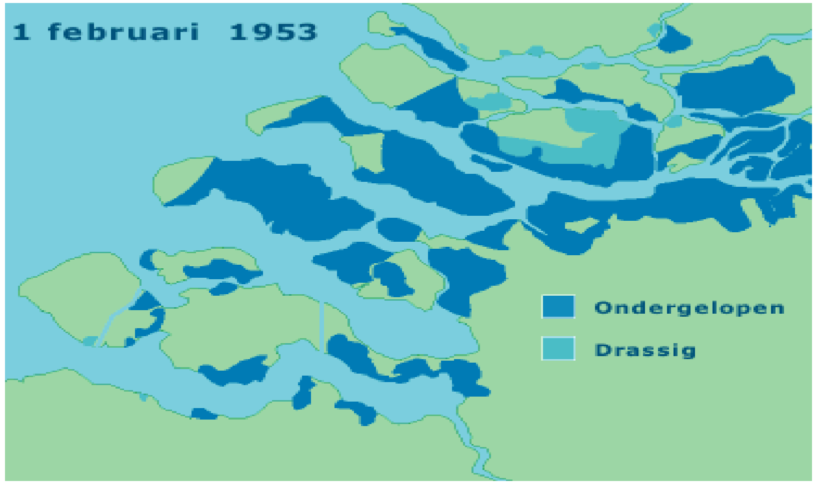
The Netherlands without flood defences



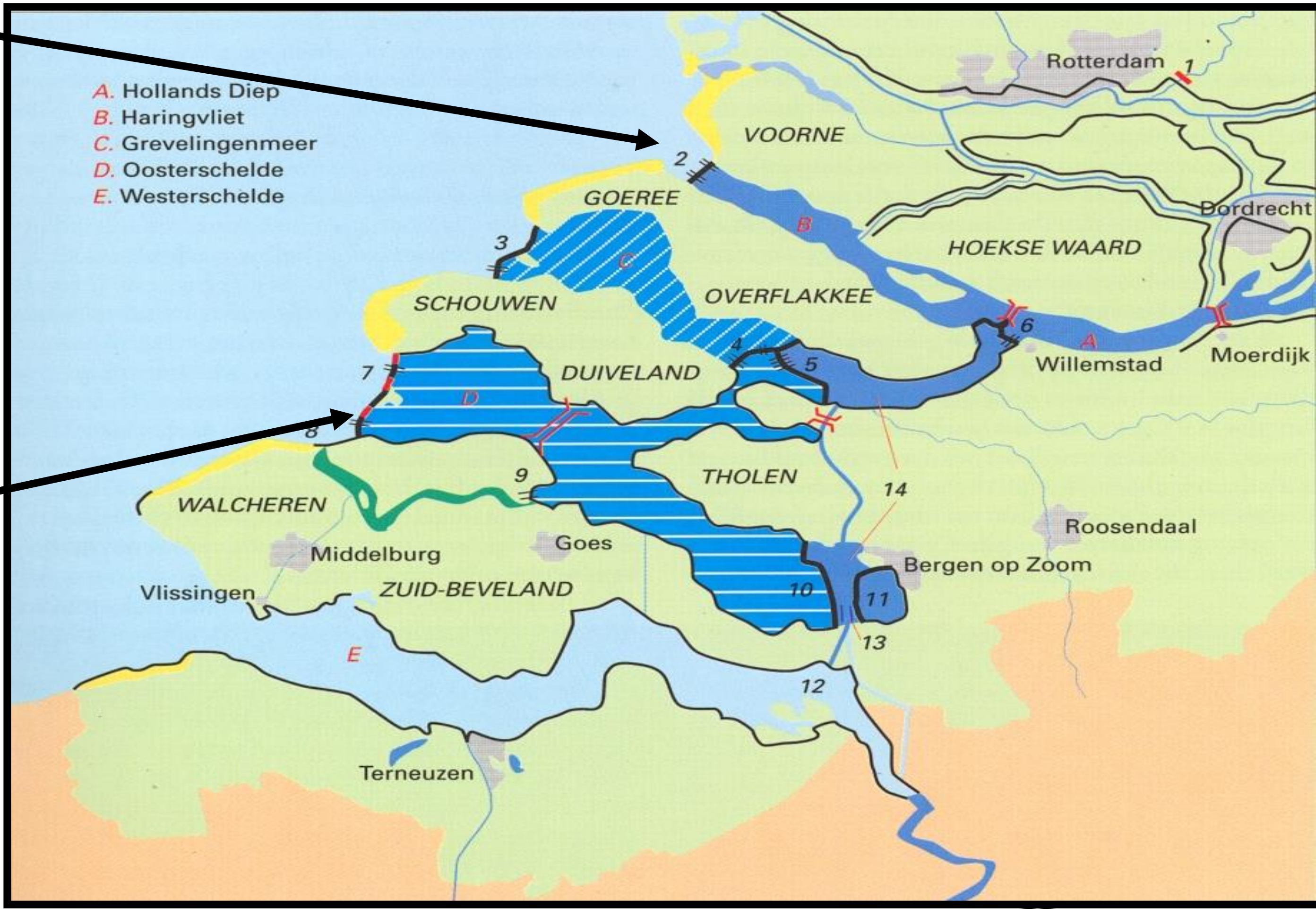
Storm surge in 1953

- 175.000 ha
- 1.800 deaths





Delta Works


A. Hollands Diep
B. Haringvliet
C. Grevelingenmeer
D. Oosterschelde
E. Westerschelde
Rotterdam
VOORNE
GOEREE
Dordrecht
HOEKSE WAARD
OVERFLAKKEE
SCHOUWEN
Willemstad
Moerdijk
DUIVELAND
THOLEN
WALCHEREN
Roosendaal
Middelburg
Goes
Bergen op Zoom
Vlissingen
ZUID-BEVELAND
Terneuzen
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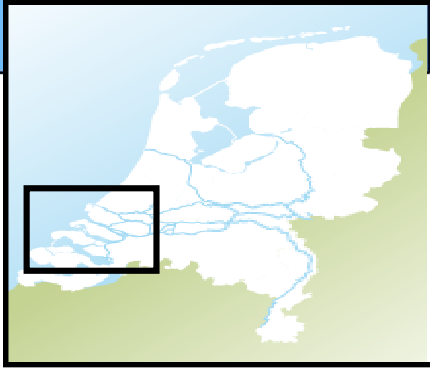
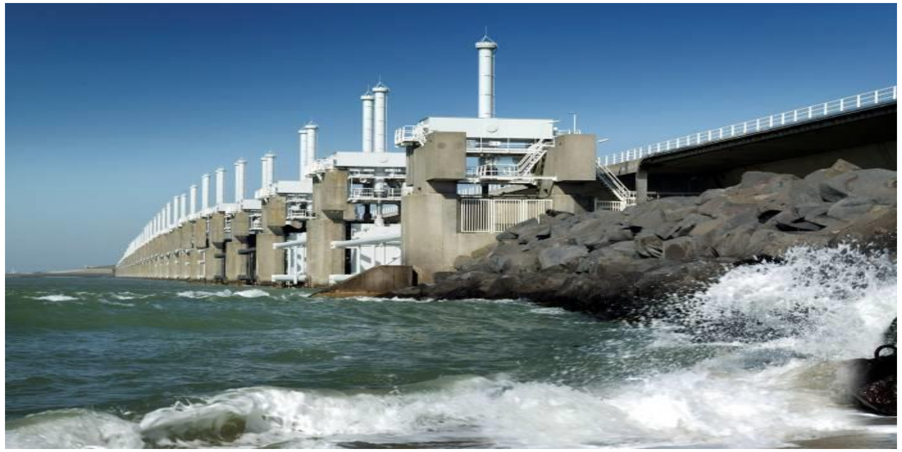
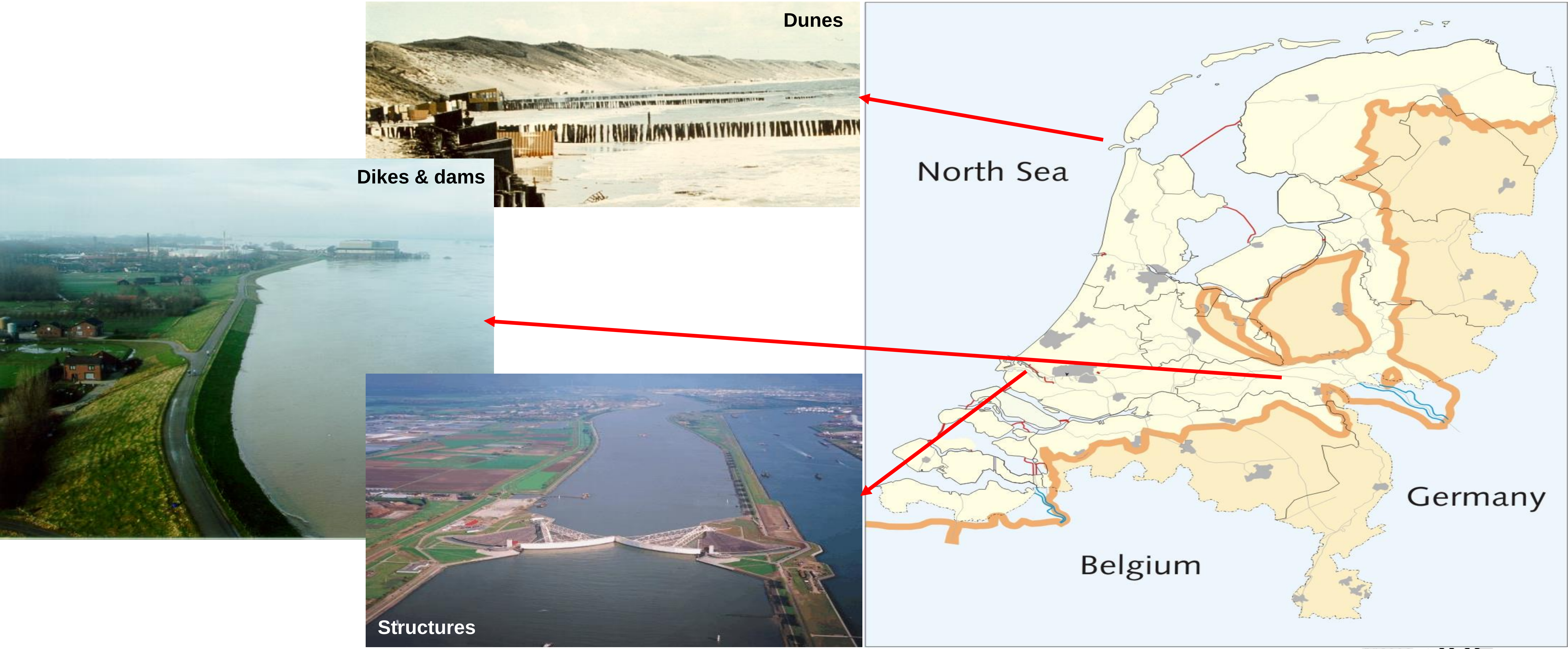


The Oosterschelde storm surge barrier



The Maeslant storm surge barrier

Flood defense system



New approach towards flood protection

Serious flood risks in 1993 and 1995 were a warning: something had to be done. 1995: evacuation ¼ million people.

Reinforcement of dikes was not enough rivers had to be given more room to ensure flood-safety in the future.

Ministry of Infrastructure and Environment developed ‘**Room for the River’** Programme

Room for the River Programme

Two aims:

1. Safer Dutch river areas by 2015.
   Safety for 2-4 million inhabitants

2. To give local governments a chance to enhance their **spatial areas** at the same time

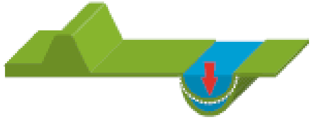
Room for the River – facts and figures

- A variety of measures
- Investment € 2,3 billion (price level 2009)
- Completion in 2015
- Decentralized planning and execution

- Approx. 150 families had to be relocated
- Approx. 50 farms have to be relocated
- 1280 ha decrease agricultural land
- 1852 ha increase of nature
- 20 million m^3 soil removal

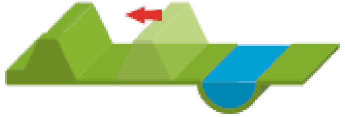
Room for the River

How we are making room for the river



Deepening summer bed
The river bed is deepened by excavating the surface layer of the river bed. The deepened river bed provides more room for the river

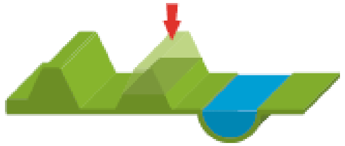
Water storage
The Volkerak-Zoommeer lake provides for temporary water storage when exceptional conditions result in the combination of a closed storm surge barrier and high river discharges to the sea.



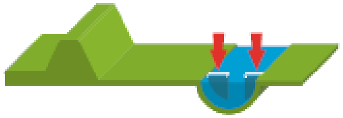
Dike relocation
Relocating a dike land inwards increases the width of the floodplains and provides more room for the river.

Strengthening dikes
Dikes are strengthened in areas in which creating more room for the river is not an option

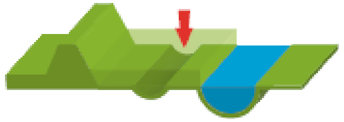
High-water channel
A high-water channel is a diked area that branches off from the main river to discharge some of the water via a separate route.



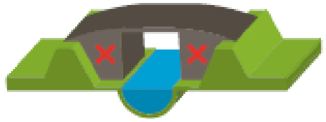
Lowering of floodplains
Lowering (excavating) an area of the floodplain increases the room for the river during high water levels.



Lowering groynes
Groynes stabilise the location of the river and ensure that the river remains at the correct depth. However, at high water levels groynes can form an obstruction to the flow of water in the river. Lowering groynes increases the flow rate of the water in the river.

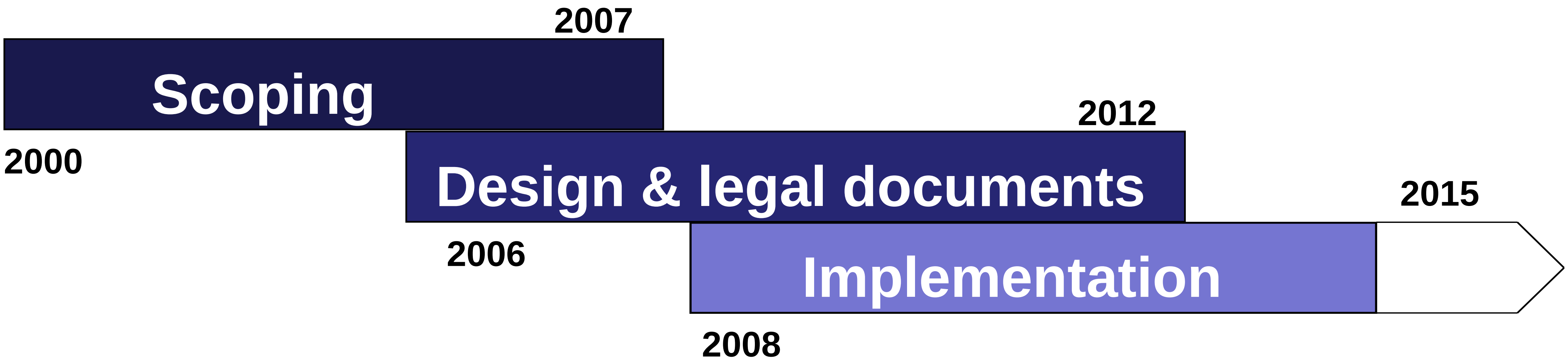


Depoldering
The dike on the river side of a polder is relocated land inwards and water can flow into the polder at high water levels.

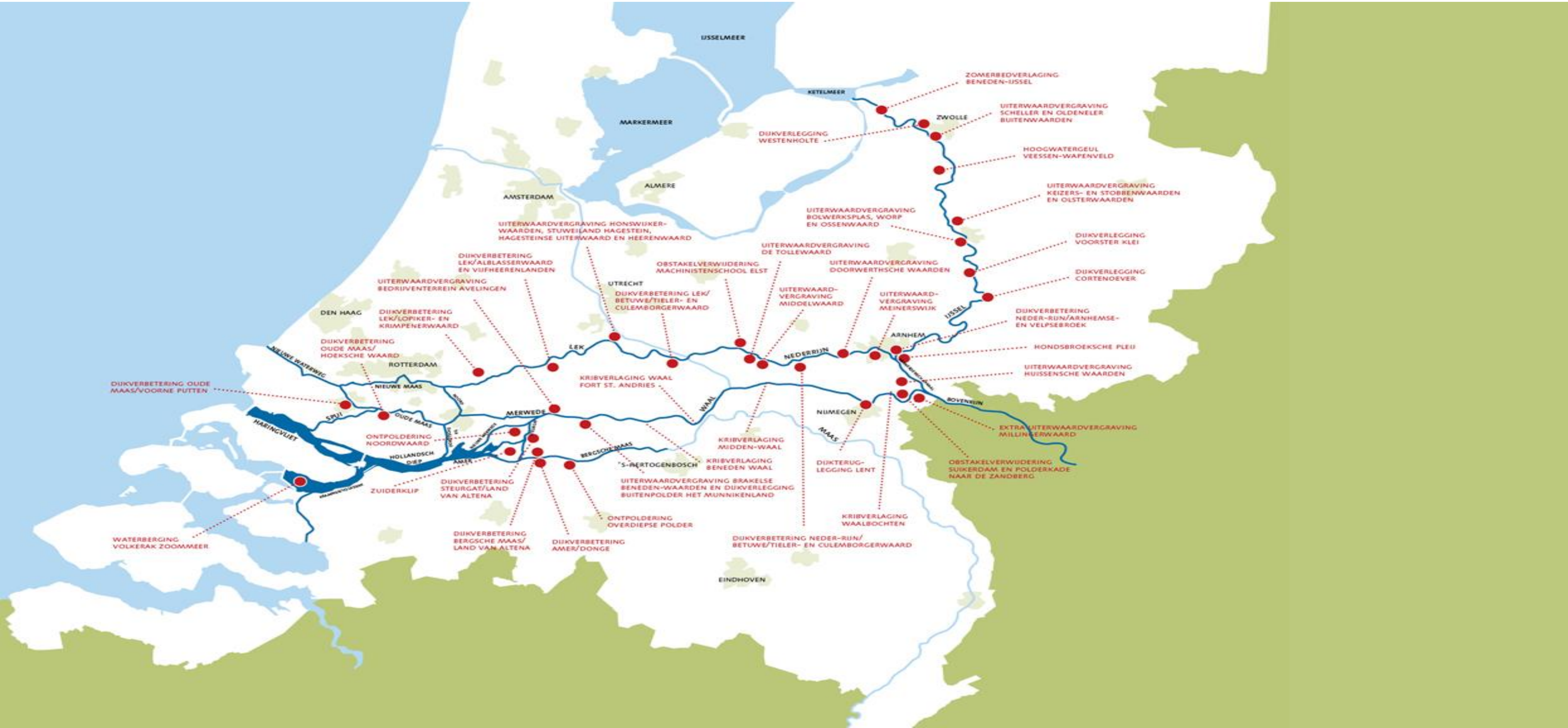


Removing obstacles
Removing or modifying obstacles in the river bed where possible, or modifying them, increases the flow rate of the water in the river.

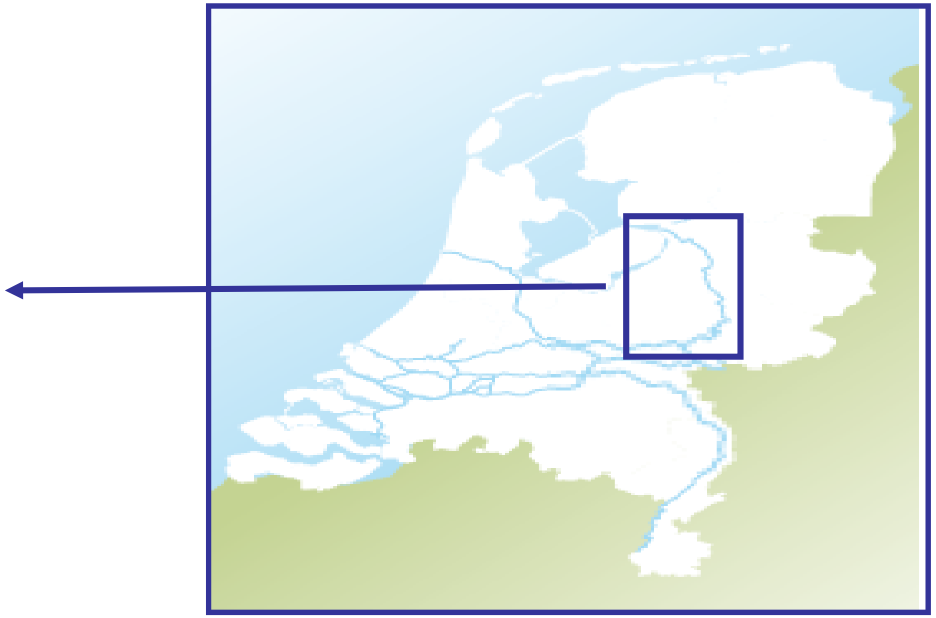
Process


2007
Scoping
2000
2012
Design & legal documents
2006
2015
Implementation
2008

More than 30 Room for the River projects

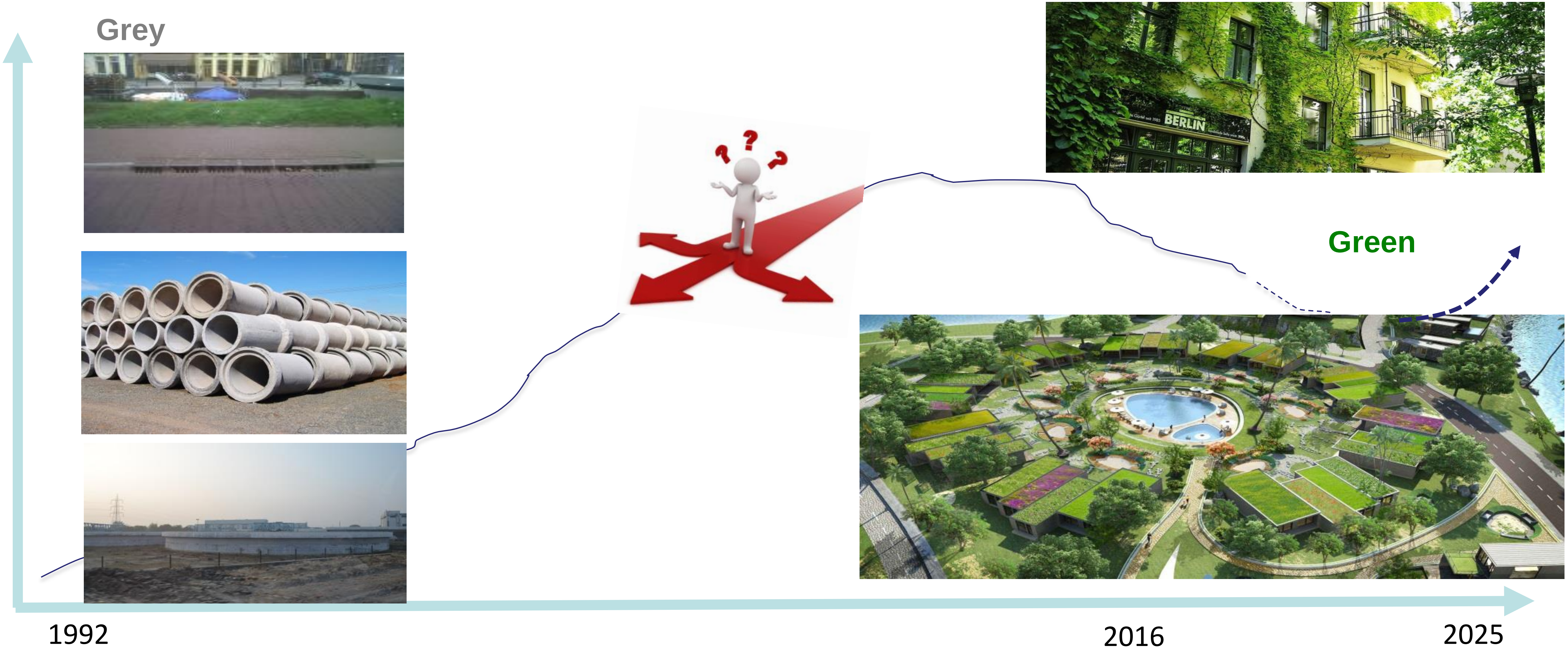


Room for the River: IJssel project



New bridges

EU Infrastructure Investments



Challenges

- Combining green, blue and grey at a scale

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Challenges

- Combining green, blue and grey at different scales

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