Regreening the Sinai

Vision and Pilot Project Concept Design

May 2024

the WEATHER MAKERS holistic engineering

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Definitions and abbreviations

Eco Oasis®:	Core process within RBD and based on photosynthesis to produce liveable soils, biomass and freshwater from salty coastal sediments and seawater. The main components are resource section, salt-/freshwater trains, sediments revitalizing section, livestock section and composting section. All of which are partly within a greenhouse type of structure
FEED	Front End Engineering Design
Liveable soil	Soils rich of nutrients and active microbial communities
Pilot Project	Anticipated project in the Sinai in the vicinity of Lake Bardawil with the purpose to regreen 1 km^2
RBD:	Resource Based Dredging
Resource Based Dredging:	Use of coastal sediments and seawater to produce the building blocks (freshwater, biomass and liveable soils) for watershed wide ecosystem regeneration
Resource section:	Section with basins or tanks where mineral and/or nutrient concentrations of water are adapted to desired levels
Salt-/freshwater trains:	Set of in series connected water bodies (transparent cylindrical tanks or basins) with a constant flow of water throughput where an aquatic diverse food web is naturally grown
TWM:	The Weather Makers
WWER:	Watershed Wide Ecosystem Regeneration

1 Summary

Watershed Wide Ecosystem Regeneration

The world is in danger of runaway warming due to biosphere mismanagement by humanity[1]. With an ever-increasing human population extracting value from Earth, the world faces severely degrading ecosystems. Over 1.3 billion people are affected by degrading agricultural land. It has never been so abundantly clear that we need functional ecosystems to support the complex life forms that live on Earth. A biosphere producing ecological value is the basis for all value creation.

We need to regenerate ecosystem on a large scale to restore our biosphere, if we don't everything will be lost! Together with renowned researchers we arrived at the Sinai Peninsula where biosphere restoration would have the largest upside in ecologic, social and economic values. The Weather Makers have the ambition to support the local community and the population of Egypt to turn the Sinai into the lush Garden of Eden it used to be.

Successful regreening of deserts asks a watershed wide holistic approach. The watershed scale allows to properly address the complex interconnection between fauna, flora, soils, water, atmosphere… and to harvest the multitude of positive impacts that regreening at watershed scale can deliver.

Figure 1-1. Impression of a regreened Northern watershed of the Sinai

Resource Based Dredging

In order to successfully regenerate an ecosystem on degraded lands – with both shortage of water and soils with lack of nutrients, microbial activity and water holding capacity – we propose Resource Based Dredging (RBD). The core of this method is the *Eco Oasis®* that uses fertile coastal sediments and seawater to grow aquatic food webs that naturally produce freshwater, grow biomass (trees, plants, etc.) and build liveable soils. With building soils, we mean that an optimal composition of soils can be obtained by dredging sediments from different predefined locations on the basis of soil investigation campaigns. The composition of these sediments can be improved by different dredging and mixing techniques, which then will be used as input to the process of natural fertilizing and biomass growth in the Eco Oasis®.

We have geared up with a dredging company to develop Resource Based Dredging. The added values of the dredging industry in regreening are multiple. Besides the capability of dredging/excavating large amounts of sediments, the industry has the capability to optimize the transport of sediments (by means of water, road, pipelines), to carry out the required essential (dry) earth works with a strong geotechnical knowledge and the capability of setting up and manage large scale infrastructural projects. Last but not least the industry has the capability of project development and organisation (governance and financing in PPP, concessions, etc.).

Figure 1-2. Activities contributing to large scale ecosystem regeneration. From left to right coastal dredging, segregation basin, pumping station and terrace structures.

[1] Biosphere mismanagement: over the past 12,000 years humanity have reduced the overall amount of living things on Earth (the biosphere), to less than half of what existed before. We have reduced the planet's climate management system to half its original size, while exponentially increase the greenhouse gases concentrations into the atmosphere

Eco Oasis®
The origin of the Eco Oasis® is based on more than 50 years of work by Professor John Todd on living technologies. Mr. Todd is a pioneer in ecological engineering, one of the founders of The New Alchemist Institute, RSENR research professor, distinguished lecturer and Gund Fellow. Mr. Todd collaborates with The Weather Makers since 2017 and so far, several dedicated studies and experiments have been jointly carried out which all contributed to the design of the Eco Oasis®.

A flow chart of the main components of the Eco Oasis® is presented below in Figure 1-3.

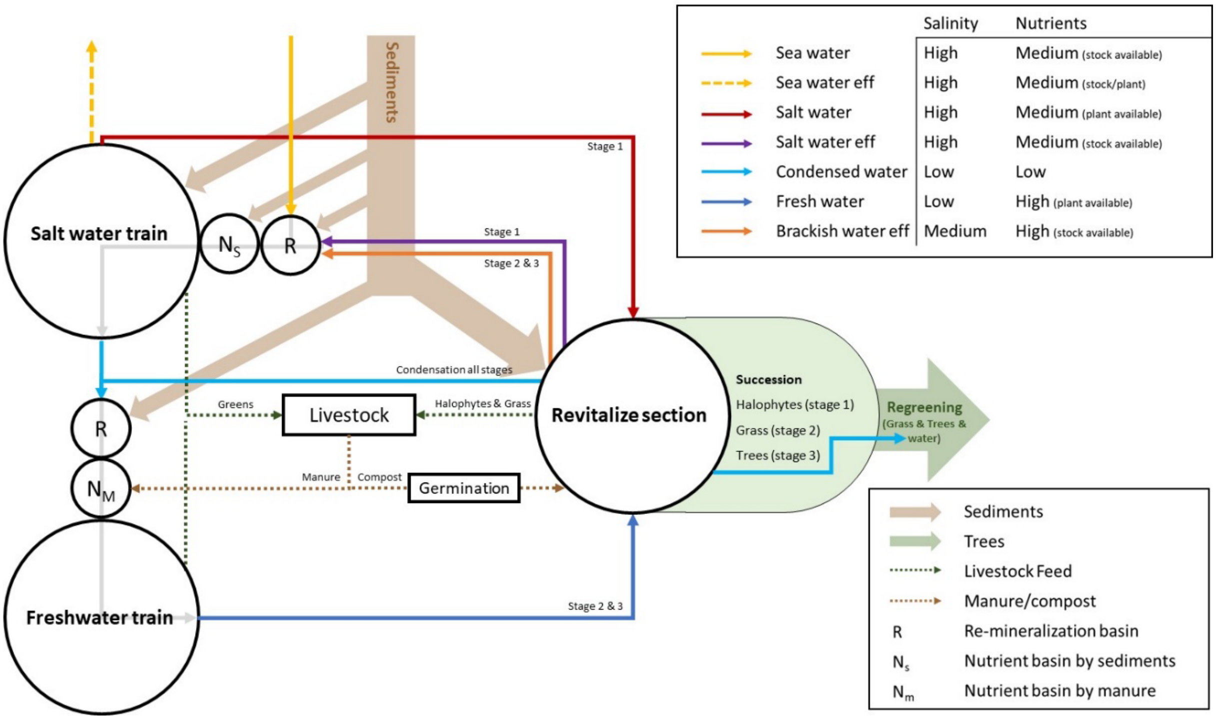


Figure 1-3. Flow chart of the Eco Oasis®. Note that the salt water train, the freshwater train and revitalize section will be in greenhouses, preferably dome shapes because of their excellent passive water harvesting potential

Top left of the flow chart shows sediments and seawater, the input elements of the Eco Oasis®. The sediments are used both in the revitalization section and as a source for minerals and nutrients in the dedicated basins. The concentration of nutrients and minerals in the seawater is optimized before entering the salt water train. The latter is a set of water bodies (stored in transparent cylindrical tanks or basins) connected in series with a constant flow of water through all basins. In the first part of the salt water train the ideal population of phytoplankton grows due to the controlled water quality inflow. This is a key aspect of the Eco Oasis®, they form the basis of the optimal functional food web. In the subsequent parts of the train other organism develop, such as zooplankton, crustaceans, worms and snails. In the last part of the train target fish species are grown. The combined set of organisms is a functional aquatic food web with the main purpose to recycle nutrients in order to make them available for plant growth.

As shown in the flow chart, the nutrient rich (salt) water from the salt water train will flow to the revitalize section (red arrow) during stage 1. During this stage halophytes will be grown on the sediments and this process will reactivate the microbial activity in these sediments. In the meantime, fresh water is harvested by means of evaporation from the salt water train in the greenhouse. This water is fed to a freshwater train to grow a freshwater food web and make nutrient rich freshwater. This nutrient rich water will be used to further revitalize the sediments during stage 2 and 3. In stage 2 to grow salt tolerant grasses and in the concluding stage 3 to grow trees. In addition, some nutrient recycling loops are closed by the use of livestock combined with composting techniques, as indicated in the flow chart of Figure 1-3.

The revitalizing stages 1 is estimated to take 9 months, stage 2 and 3 are estimated to both take 3 months respectively. Hereafter the newly grown trees and revitalized sediments are ready to be used in the regreening. Planting is recommended to be combined with the Groasis Waterboxx®. This is an intelligent plant cocoon that reduces the water use of trees and plants with 90% compared to drip irrigation techniques. The Eco Oasis® produces sufficient freshwater for the boxes to function as desired.

Pilot project

We have identified that a *pilot* project in regreening is of essence to optimize the main technical challenges and provide a proven concept for upscaling our solution with a solid business case and secure financing. The proposed pilot would require almost 2 years start-up time in order to regreen 1 km^2 (100 hectares) in about 3 years. The total cost (CAPEX + OPEX) is estimated to be 10-12 Mio Euro for the 5-year pilot.

Figure 1-4. Plan view of the 1 km2 regreening site and adjacent Eco Oasis®. The close up of the grass grid, are (dried) salt tolerant grasses grown in the second stage of the revitalizing section (see Figure 1-5 below).

Figure 1-5. LEFT: example of regreening site in Kenya with the use of Groasis Waterboxx® (project carried out by the Worldlife Foundation). RIGHT: increasing the water infiltration and retention capacity of the soil using dried grass (China).

2 Introduction

Large scale ecosystem regeneration is required to create successful impact on the climate and functionality of the ecosystems. The ‘’business’’ of regenerating severely degraded landscapes may ultimately be one of the most meaningful developments there is on earth to counter global warming and climate change. For industrial, financial, governmental or other partners who are joining on this journey of regeneration, it is not only inspiring to join a development which will be beneficial to their enterprises, it is also most inspiring that they will be part of a movement that is fundamentally about regeneration.

As the dredging company provides solutions for global challenges and creates sustainable value for customers, stakeholders and the wider society, it is not difficult to conclude that ecosystem regeneration is a perfect match to the dredging company. Considering the Bardawil Lake Development Project, the dredging company has demonstrated in the previous years to be committed to play a pioneering role in proactively investigating technological solutions to tackle large challenges.

The Weather Makers (TWM) intents on acting against climate issues by bringing together knowledge, skills and networks (in amongst others hydraulics, morphology, meteorology, ecology, hydrology and economy) to conduct and facilitate projects using holistic engineering and nature-based solutions aimed at restoring the planet. TWM have the objective to create functional ecosystems at the basis of society. We strive to develop Watershed Wide Ecosystem Regeneration at the broken continental divide regions to restore hydrological cycles.

We are proud to be one team with the dredging company to secure the Bardawil Lake Development Project and during the course of the road to Bardawil we have positioned ourselves perfectly to make the next step: large scale regeneration of the northern Sinai.

There are political, cultural and organizational challenges to overcome for successful implementation. This report focusses on the **technical challenges** and will elaborate on the vision.

VISION FOR ECOSYSTEM REGENERATION

Loess Plateau China in 2017

Left image: same location in 1995

1 Watershed Wide Ecosystem Regeneration

1.1 Why regreening the Sinai

With an ever-increasing human population extracting value from Earth, the world faces severely degrading ecosystems. Estimates indicate that up to 25% of all land worldwide is currently highly degraded (FAO, 2011). Over the last two decades, approximately 20% of the Earth's vegetated surface shows persistent declining trends in productivity, mainly as a result of land and water use (UNCCD, 2017). Over 1.3 billion people are affected by degrading agricultural land. It has never been so abundantly clear that we need healthy and functional ecosystems to support the complex life forms that live on Earth. For humans, a healthy biosphere producing ecological value is the basis for all value creation.

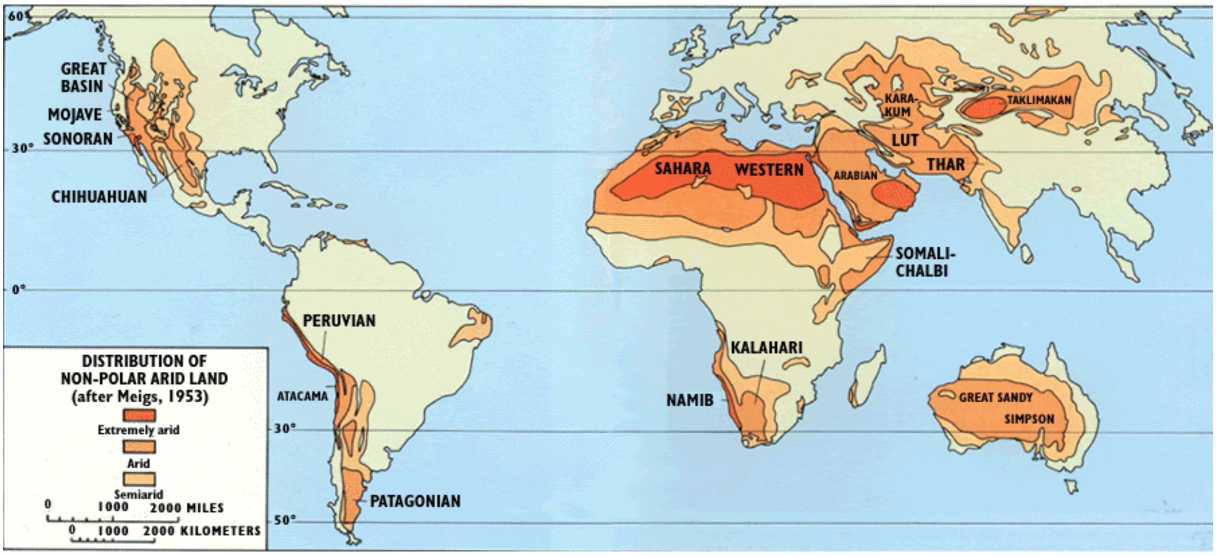


Figure 1-1. World Map showing the distribution of deserts on Earth (Source: pubs.usga.gov)

Unlike degraded landscapes, healthy ecosystems transform solar heat and energy into photosynthesis and evaporation, inducing cloud formation and precipitation, thus helping to cool the Earth. Several studies are documenting the impact of evapotranspiration and temperature on the hydrological cycle (Millán, 2014 & Makarieva et al., 2010). Based on these studies, one can state that when a large part of the Sinai Peninsula will be regreened, the evapotranspiration will significantly increase and the air temperatures will be lower, allowing condensation, thus cloud formation and eventually precipitation as the moist air is moving inland and gaining altitude (Figure 1-2). Meanwhile, the regreened area helps sequester enormous amounts of greenhouse gases. Ecological restoration of ecosystems is therefore crucial to mitigate global warming and climate change.

Functional ecosystems increase social value and security. Many jobs can be created on healthy functioning ecosystems. Food can be produced in abundance of rich soils and clean waters. Once desertification is turned around and re-greening takes place, people can sustain a healthy life on the lands they live on. Once they can start trading the products provided by the earth, social unrest as well as large scale migration of people who are fleeing from deeply impoverished situation will be halted.

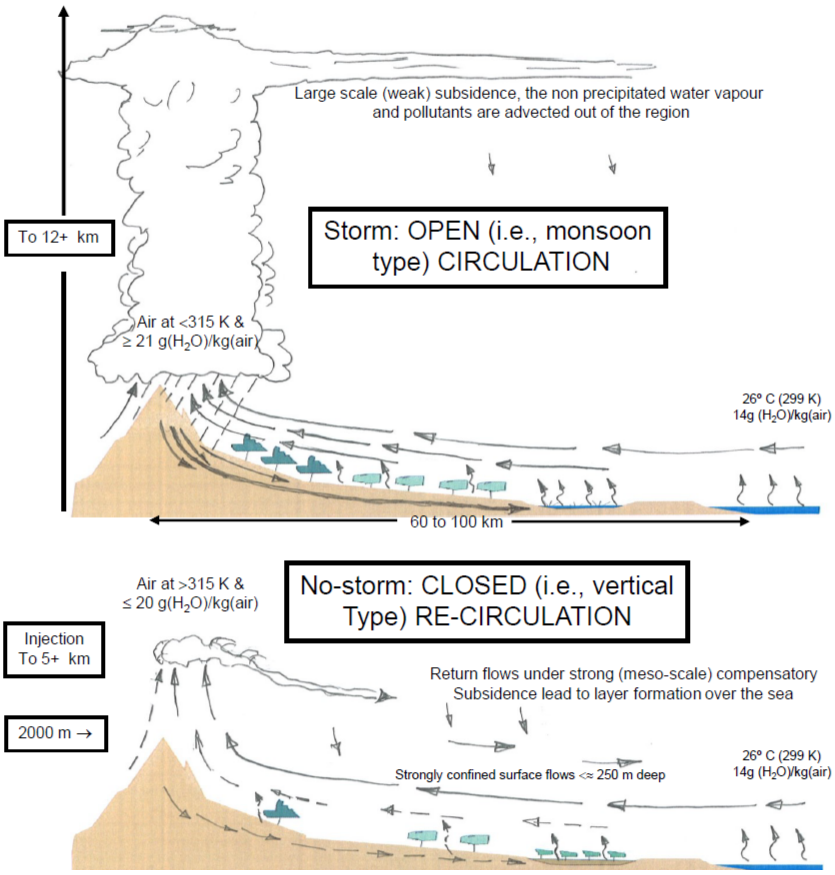


Figure 1-2. The influence of vegetation on evapotranspiration, temperature and the hydrological cycle in a typical summer situation along the Spanish coast (Millán, 2014). The upper image shows what happens when there is sufficient vegetation on land. It basically adds moisture to the initial moisture (14g (H20)/kg air) by evapotranspiration and therefore, as the moist air mass is reaching higher altitude, it has sufficient moisture (>= 21g/kg) to form clouds and precipitate. On the opposite, the lower image shows that if not sufficient vegetation is present, the threshold of >= 21g/kg is not reached and there is no clouds formation that will trigger precipitation. This water is lost from the local hydrological cycle.

The Weather Makers have the ambition to support the local community and the population of Egypt to turn the Sinai into the lush Garden of Eden it used to be. We have geared up with the dredging company to develop the holistic approach and executional implementation to achieve this ultimate goal. And there is more… TWM have discovered that a greener and cooler Sinai can bring more moisture to the region; due to its topographic position at a continental divide, see Figure 1-3.

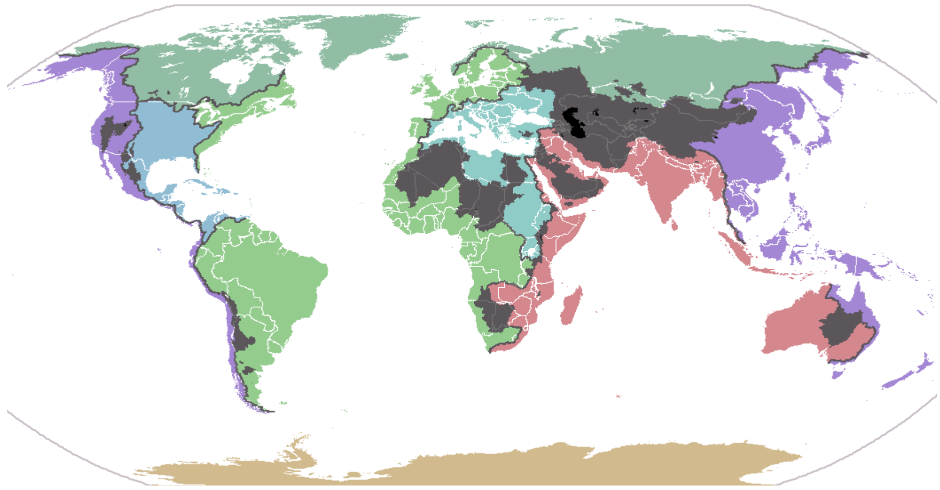


Figure 1-3. The major basins (watersheds) in the world that drain water into the oceans and seas. Dark grey areas are endorheic basins that do not drain to the ocean. The borders between the basins are called continental divides, high elevated areas that split weather systems. A continental divide crosses the Sinai (image source UN)

A cooler Sinai will even positively influence the larger weather systems that cause extreme weather around the Mediterranean and the Indian Ocean watersheds. Regreening the Sinai might be the accelerator to stop global warming.

1.2 How to regreen the Sinai

As a consequence of ecosystems bouncing back, economic value will soar. TWM's research and development indicate that the first significant benefits from the revitalisation of marine and land-based ecosystems will be felt in a few years, as fish start to return in natural habitats and smallholder agriculture starts to bear fruit. Our studies show that in the long term large-scale sustainable fisheries can grow in Lake Bardawil (the dredging company & TWM, 2021). We focus on creating ecosystem function while we regenerate the system.

Successful regreening of deserts asks a watershed wide holistic approach. The watershed approach allows one to properly address the complex interconnection between fauna, flora, soils, water, atmosphere… and to harvest the multitude of positive impacts that regreening at scale can deliver. Large scale regreening should start by restoring the ecological functions of coastal ecosystems. By restoring the coastal systems, we can boost the food production of the nearshore and obtain fast track benefits, while kick starting the restoration of the hydrological cycle by enhancing the evapotranspiration potential on the coast through habitat restoration. These coastal areas also offer the potential to accelerate the restoration of land by strategic reuse of coastal sediments that contain the much-needed organic matter and nutrients.

We have summarized three schematic main steps as the building blocks for Watershed Wide Ecosystem Regeneration (WWER):

- Step 1: Regenerating the Coastal Lagoon and Wetlands: Ready for upscaling, because sufficient proven evidence of successful projects is available in which nature-based solution naturally improve primary productivity of the coastal zone and create significant ecological, social and economic value.
- Step 2: Regreening the Desert: Many examples throughout the world demonstrate the successful regreening of degraded lands. However, pilots are recommended to be conducted to demonstrate the economic potential of using marine sediments.
- Step 3: Restoring the Hydrological Cycle: On which there is academic research carried out to validate how to efficiently regenerate the water cycle[2].

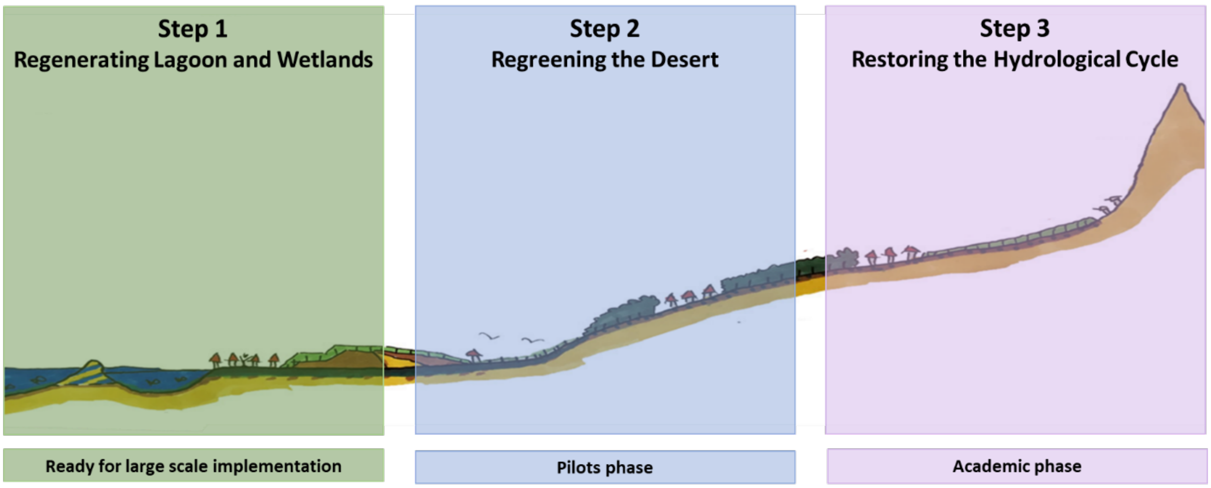


Figure 1-4. Steps in watershed wide ecosystem regeneration and status for implementation, defined on the basis of pre-feasibility studies for the Sinai project.

Since 2017, pre-feasibility studies have been carried out to investigate the conceptual approach to regenerate the northern Sinai watershed. The first step, regenerating the lagoon and wetlands of Lake Bardawil, is brought to a concept design level and peer reviewed by renown international, including

[2] Research is on-going at WETSUS institute https://www.wetsus.nl/research-themes/natural-water-production/

Egyptian scientists. The concept design for the lake is prepared and presented on Presidential level. The regreening of the Sinai was part of several studies, however a full feasibility study, with more in-depth research needs to be conducted.

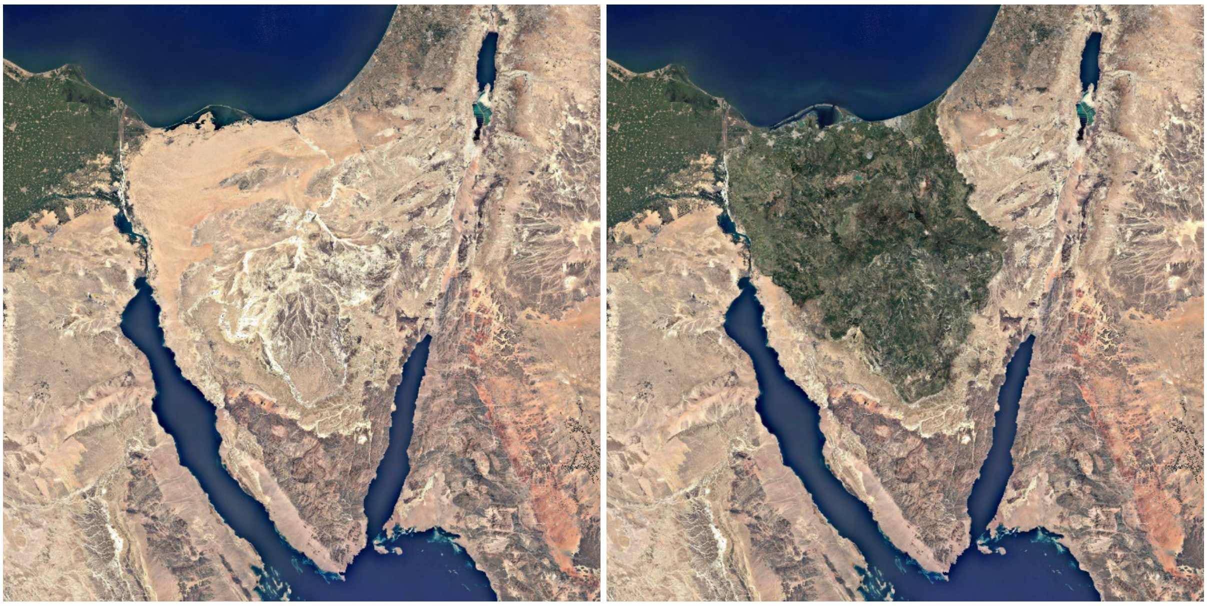


Figure 1-5. Current situation (left) and an artist impression of a fully regenerated Sinai (right)

The previously performed studies helped us to get a rudimentary understanding of the key dimensions of research and engineering. It also gave us clear insight in the competencies we need to get large scale regreening designed and implemented. It helped understanding the potential benefits for local communities: increasing livelihood, food, water, jobs, peaceful lives and a sustainable future.

We have identified that a regreening pilot project is of essence to overcome a set of technical challenges and provide a proven concept for upscaling our solution and deliver a solid business case.

1.3 Technical challenges in high degraded lands

The main technical challenges which have to be overcome to revitalise the Sinai desert are:

- Shortage of nutrients and microbial activity in the soil
  Degraded lands do not have the required nutrients and microbial activity needed for growth of vegetation.
- Shortage of water
  Low precipitation in combination with high evaporation rates lead to insufficient water for growth of vegetation.
- Shortage of soil structure, water retention and infiltration capacity of the soil
  In the Sinai sporadic rainfall occurs, but these are relatively small amounts over a year and often captured in extreme events. The current (top layer) soils are not able to retain and/or infiltrate this water coming down in an extreme event. This water is almost directly 'lost' by runoff, often leading to flash floods and resulting in more soil erosion, casualties and fatalities downstream.

In order to overcome the above challenges and successfully regenerate an ecosystem on degraded soils, we propose the so-called Resource Based Dredging solution. This approach is supported by a set of experts and participating in the development of the Sinai plans. Some of those experts, amongst others, are John D. Liu, Millán M Millán, John Todd, Daniel Halsey, Rhamis Kent, Li Rui and Tim Flannery.

1.4 Added values of the dredging industry in regreening

Considering the requirements for regreening deserts, it is clear that the dredging industry can play an essential role:

- Capability of dredging/excavating sediments as resource to build liveable soils and biosphere. With building soils, we mean that sediments can be dredged from predefined locations on the basis of a soil investigation campaign. These soils can, by using different methods be mixed to improve the composition which will be used as input to the process of fertilizing and building biosphere;

- Capability of transporting sediments and water by means of water, road, pumping through pipes;

- Capability of carry out essential (dry) earth works with a strong geotechnical knowledge;

- Capability of setting up and managing large scale infrastructural projects;

- Capability of project development and organisation (finance, PPP, concessions, etc.).

Figure 1-6. Round the clock and starting top left: Cutter Suction Dredger, large scale sediments disposal site, large scale earth works and a pumping station.

2 Resource Based Dredging

2.1 Technical concept

The concept of the proposed solution “Resource Based Dredging” (RBD) is to use coastal sediments for terrestrial ecosystem regeneration. The baseline requirement for this approach is that sediments, with a high organic content and rich of nutrients and minerals, are available in the coastal zone. From an economic perspective these sediments should be relatively easily accessible for dredging and disposal.

The concept is fully applicable for the northern Sinai, but can potentially be fulfilled at many locations in the Southern Mediterranean Sea and a lot of other locations in the world, making RBD on a very large scale applicable (refer to Section 3.7). Key to success is to build liveable soils that can hold water, so that infiltration and retention overtake evaporation on the long term. The flow chart in Figure 3-3 shows on a high level the Resource Based Dredging solution.

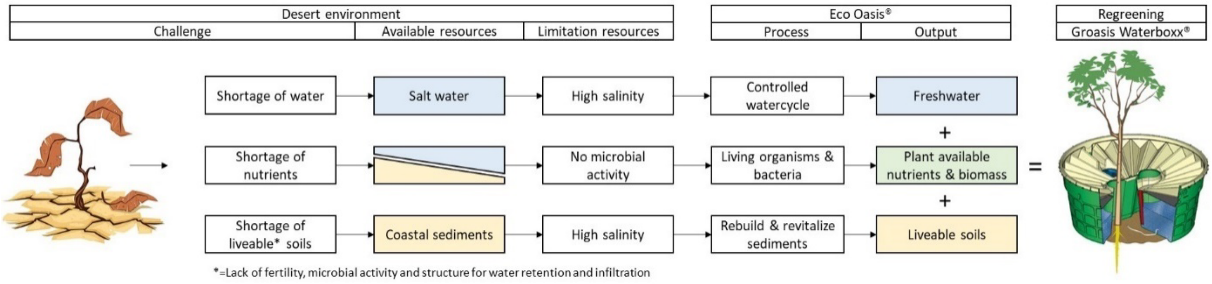


Figure 2-1. Flow chart showing the concept of Resource Based Dredging

In order to overcome the technical challenges (far left in Figure 2-1), the resources from the coast which are used are potentially fertile sediments and seawater. They can be obtained by dredging, but the (high) salinity and low microbial activity form a limitation to the direct use of these resources in regreening. To overcome these challenges the Eco Oasis® is introduced, which is capable to produce the building blocks for regreening the desert. The newly grown biomass produced with the Eco Oasis® will require irrigation during the first part of its lifetime. This water is also produced by the Eco Oasis® and can be remained to a limited amount when the planting is combined with the Waterboxx®. This box, developed by Groasis, is a product capable of providing water to the newly planted tree at high efficiency (low water losses to the surroundings) and has a successful track record. In the next paragraphs the different processes of the Eco Oasis® are further described.

2.2 Eco Oasis®®

2.2.1 Introduction

The objective of the Eco Oasis® is to naturally produce liveable soils, biomass and freshwater from (salty) coastal sediments and seawater. The origin of the Eco Oasis® is based on more than 50 years of work by Professor John Todd and his living technologies. Mr. Todd collaborates with TWM since 2017 and so far, several dedicated studies and experiments have been jointly carried out which all contributed to the design of the Eco Oasis® as currently proposed. The Weather Makers B.V. (Chamber of Commerce number 67946275) was granted a patent for the Eco Oasis® with number 2028987 on February 24, 2023, issued in The Hague, Netherlands.

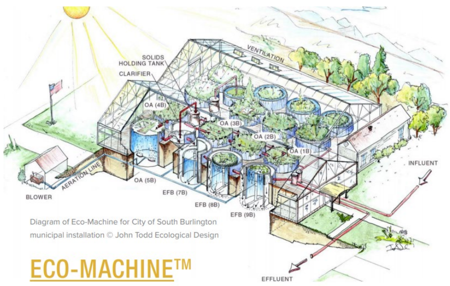


Figure 2-2. John Todd and an Eco Machine example project: The Installation for the South Burlington municipality

2.2.2 Main input and output

Figure 2-3 shows an overview of the inputs, processes and outputs of the Eco Oasis®.

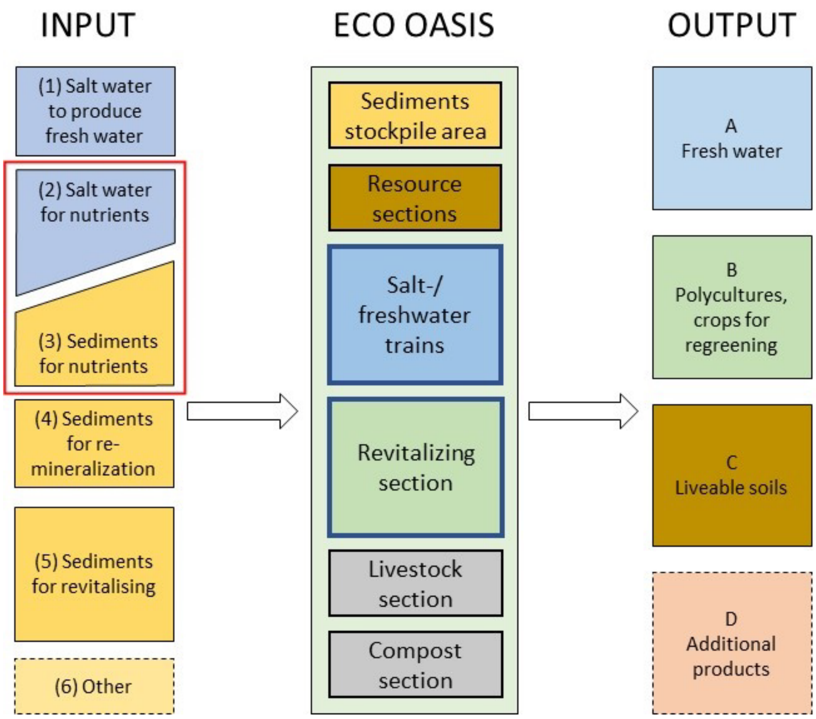


Figure 2-3. Production site input and output overview. Red box is flexible input

The main inputs for the Eco Oasis® are sediments and salt water. The Eco Oasis® produces a "functional biosphere", meaning it generates revitalised soils with microbial communities and different types of plants, trees and freshwater, all in a natural way.

The desired output A (freshwater), B (biomass), and C (soils) determines the required input amounts, which are further specified in the list below, with the numbers within the brackets indicating the input (see Figure 2-3):

- The amount of salt water required to produce freshwater (1) is determined by the freshwater output needed for both the processes within the Eco Oasis® as well as the freshwater that is used for drip irrigation in the regreening;
- The required salt water (2) and sediments (3) for nutrients is indicated with the red box in Figure 2-3. This should be optimized project specific[3];
- The required volume of sediments for re-mineralization (4) is mainly determined by the available concentrations of silica in the water. Silica is used in the freshwater and salt water trains of the Eco Oasis® for the growth of diatoms, which will be further explained in the upcoming paragraphs;
- The amount of sediments to be revitalised (5) and used in the regreening is determined by the required output C of liveable soils;
- Other inputs (6) are energy for supporting systems in the Eco Oasis®, seeds, manpower, materials, power, etc.;

[3] , one or both elements can be used as a nutrient resource. Optimization depends on the dredging process. For example, the process water required for hydraulic transport of sediments could fulfil part (or most) nutrients input, hence an economic optimization can be achieved. It can provide opportunities in the production of freshwater.

- ➢ Additional products (D), can be fish, shrimp, artemia, salt etc. and will not be further addressed in this report.

2.2.3 Main components and processes

The Eco Oasis® will naturally produce liveable soils, biomass and freshwater from (salty) coastal sediments and seawater. This will be carried out through a combination of processes, of which the most important are:

- ➢ Build the optimal water quality by re-mineralizing and dissolving nutrients in the water for rapid growth of diverse aquatic ecosystems. These ecosystems are used to recycle minerals and nutrients and make them plant available;
- ➢ Rebuild and mix sediments to build the ideal composition of soils to be used in the revitalizing process. Revitalizing is carried out by activating microbial activity with successive plant growth in combination with flushing to reduce the salt concentration;
- ➢ All of this is within a controlled water cycle to produce freshwater and optimally recycle nutrients and minerals.

A flow chart is presented in Figure 2-4.

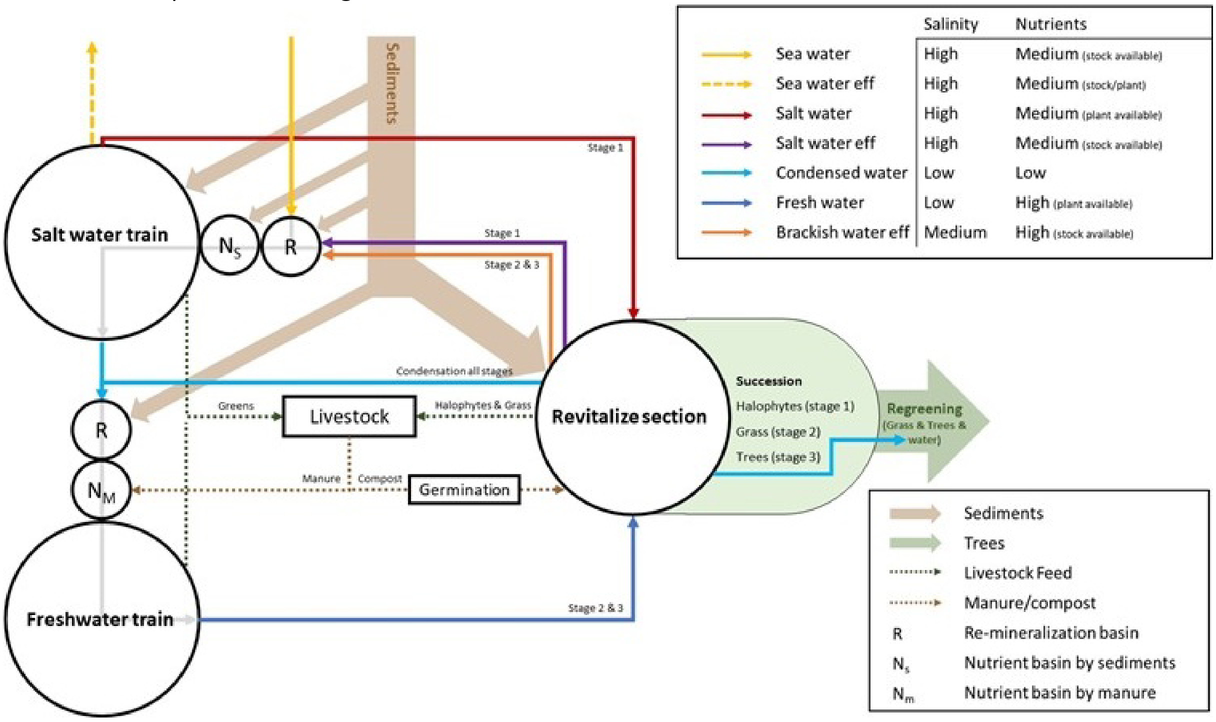


Figure 2-4. Flow chart of the Eco Oasis® with main flows of sediments, water and nutrients

The components of the flow chart are described below. Please note that the salt water train, freshwater train and revitalize section are placed within a greenhouse type of structure (preferably a dome) for passive water harvesting (see paragraph 2.2.4).

- ➢ **Sediment stock pile area**. This area consists of sediments with different characteristics, coming from the dredging process. If required, the sediments can be mixed to improve the composition before they are brought into the revitalization section (which will be described further down). The sediments can also be selected to be used in the resource section.

- ➢ **Resource section** consist of resource basins (R, N_s, and N_m in Figure 2-4) which will be designed such that an optimal water quality (ideal concentration of carbon, nitrogen, phosphorus and silica) is obtained before the water enters the water trains. Water flows through these basins. Primarily, the water will be re-mineralised by pushing the water through a granular filter bed, such that silica concentrations in the water are increased and the growth of diatoms is stimulated (see upcoming paragraph on primary production). The water quality will be further optimized by aquatic decomposing. Sediments can be added manually to feed heterotrophic micro-organisms living in this basin, which will make certain enclosed nutrients available. Additionally, this basin can be subject to the dissolution of additional fertilizers from manure.


Figure 2-5. Representations of re-mineralisation/nutrients basins on different scales

- **Saltwater and freshwater trains.** These "trains" are a set of in series connected water bodies (cylindrical tanks or basins, depending on the scale, refer to Figure 2-6) each having its own dedicated microcosmic ecosystems and collectively contain organisms from all five kingdoms of life to become a robust functional aquatic food web.


Figure 2-6. Examples of "water trains" with aquatic ecosystems (these ones are setup for waste water treatment)

The purpose of the food web is to recycle dissolved nutrients and make them available for plant growth (on land). Three main steps can be distinguished:

1. ***Primary production**:* This section consists of photosynthetic growth. The input to this section is water coming from the resource basins, which has the ideal composition of nutrients and minerals for diatom algae to flourish. The reasons for selecting diatoms as a basis for the aquatic food web inside the subsequent steps are multiple. They are the preferred foods of zooplankton and filter feeding fishes, they grow rapidly (Furnas et al., 1990) and are essential to provide a robust composition of phytoplankton to feed the aquatic food web (Kuiper et al., 2015). The basins/tanks/cylinders in this section shall have a maximized surface area and minimal depth to have as much solar energy as possible coming in for photosynthesis. However, it is important to make a proper cost/benefit analysis to determine the optimal surface area.
2. ***Aquatic growth**:* Water and diatoms flow further downstream to the aquatic growth section. In this section the ideal circumstances are created for (secondary) growth of zooplankton, macro algae, worms and snails. The diatoms generate dissolved oxygen that

will be used by juvenile fish. Worms and snails are processing organic matter, further (re)cycling nutrients.

3. ***Fish habitats****:* The fish are fed with water from the aforementioned sections rich of phytoplankton, zooplankton, worms, snails, etc. and thus food for the fish. Waste from the fish is broken down by nitrifying bacteria. Initially these bacteria process the fish excretion into nitrites and subsequently into nitrates that are fed to the plants as nutrients (in the revitalizing section). The aquaculture basins can be deeper and narrower than the other basins, because it does not require light penetration to function.

The (plant available) nutrient rich water at the end of the water trains will be used to feed the plants in the revitalizing section, see next paragraph. The solids will be harvested from time to time and used in either compost or in the resource basins.

Building the food webs in the water trains can be compared to aquaponics systems. These systems find its origin in the various works of the New Alchemy Institute in the 70s and is currently used in multiple different setup all around the world. Probably the largest installation is found in China where polyculture fish ponds are used to grow rice, wheat and other crops, with some installations exceeding 10,000 m2 (see Figure 2-7).

Figure 2-7. Aquaponics in a greenhouse setup and on a large scale at Lake Taihu in China (images from Ceresgs.com and aquabiofilter.com)

- **Sediments revitalising section**: In this section the sediments are revitalised by growing biomass (plants) over a period of several months, that will activate the microbial communities in the sediments by releasing exudates through the roots of plants. The vegetation will follow different succession steps from salt (halophytes) to brackish (salt tolerant crops/grasses) to trees. The halophytes are fed with the (plant available) nutrient rich water from the salt water trains. In the following succession steps (salt tolerant crops and trees) the sediments will be gradually flushed with freshwater. This water is passively harvested and ran through a freshwater train first, in order to make this water nutrient rich before it is fed to the plants. This process will take several months.

- **Livestock and compost sections**: Limited livestock is required to close some recycling loops. Within the water trains, plants will grow that can be fed to livestock. The halophytes and salt tolerant crops and grasses are also suitable to feed to livestock. The manure will be used in the nutrients resource basin of primarily the freshwater domes and to build compost primarily for the germination of seeds before entering the revitalizing section.

Different water trains will be setup for salt and freshwater aquatic ecosystems. In the beginning (stage 1 in Figure 2-4) only salt water trains will be setup. In the revitalizing section halophytes are grown that use the salt water. The harvested freshwater will be used to setup a freshwater train. The water coming from this train will be used in the revitalizing section (during stage 2 and stage 3, see Figure 2-4).

2.2.4 Passive water harvesting

One important aspect of the regeneration of terrestrial ecosystems in degraded areas is the shortage of freshwater. Within the concept of the Eco Oasis®, we will generate and collect freshwater by condensation of salt water inside greenhouses, preferably in dome shaped structures. Our tests show that the shape of the dome has huge advantages in terms of condensation compared to other greenhouse structures. This has to do with the relatively large surface area of the foil. The structure of the dome also increases the water production potential, due to the shape of the foil in a dome (the sharp angle of the foil to the gravity force) triggers the condensed water vapour to run down as droplets and can be collected. While these water droplets run down almost immediately, they leave an open space for more water vapour to condense.

A constant discharge will be maintained within the tanks of the water trains. Especially in the primary production tanks, the growth of diatoms will generate heat which further enhance evaporation. Provided that there is sufficient wet surface area (approximately 40% of the surface area within the greenhouse), it will have the space and time to evaporate continuously. After evaporation the salt water has been cooled down and will flow out. This way a continuous process is created inside the greenhouses with an inflow of warm salt water, evaporation and condensation of freshwater and an outflow of cooler and more saline water. The water vapor will condense against the inner foil surface of the greenhouses and can be collected with gutters. After passing through the freshwater Eco-Oases to be enriched in plant available nutrients (see further explanations), this water will be used to irrigate the grasses and trees and thereby desalinising the soils by flushing. Nutrients from the aquatic decomposing and the manure composting facility are the inputs to build the food web in the freshwater trains.

The evaporation of water in the Eco Oases will increase the humidity in the air around the production site. The amount of water vapour (relative humidity) increases even further because of evaporation taking place from the sediment and salt water basins. Fog nets could catch this water vapour and potentially increase the availability of freshwater on site even more, if the production site is located on the optimal altitude. The concept of boosting freshwater production at the site is schematised in Figure 2-8.

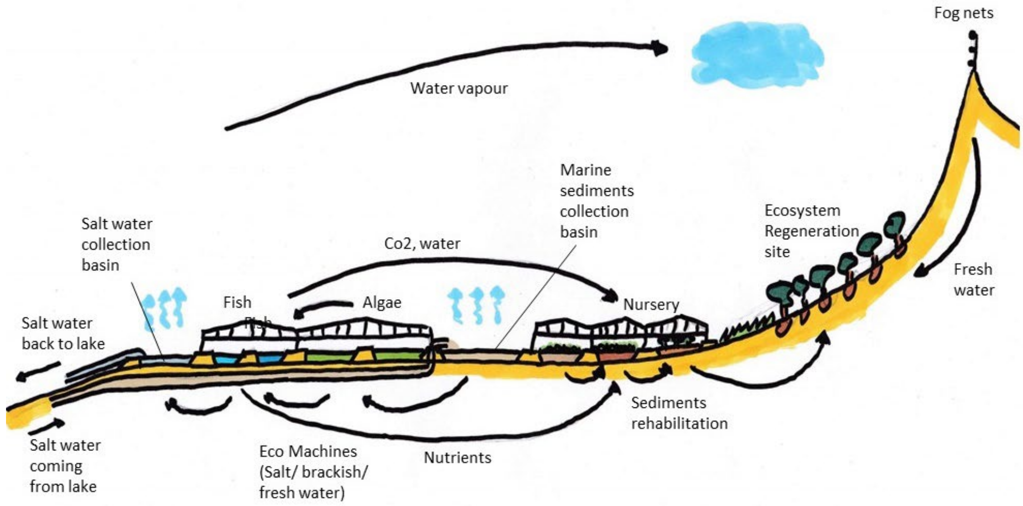


Figure 2-8. Cross section of physical relationship between the different elements of the Eco Oasis® and adjacent regreening site

2.3 Regreening

The next stage is the actual regreening of the area. The production site will provide a functional biosphere for distribution in the area. In other words, trees accompanied with liveable soils containing a flourishing microbial community and sufficient water to overcome the first 2 to 3 years of survival. TWM partners with the Worldlife Foundation to explore the use of the Groasis Waterboxx® technology. The patented Waterboxx® plant cocoon reduces the water use and trees can be planted with less water. Groasis claims that their solution uses 90% less water and that the trees planted with it have a survival rate of over 90%. The Worldlife Foundation has valuable experience using the Waterboxx® technology and shared their results as input for this report.

Figure 2-9. Groasis Waterboxx® plant cocoon (image Groasis)

According to Groasis, their Waterboxx® plant cocoon is the ideal alternative for drip irrigation. The box is made from polypropylene (plastic) and therefore it can be used 10 times. The tree needs the box 9 till 12 months to grow. When the tree doesn't need the Waterboxx® plant cocoon anymore, it can be carefully removed from the tree and re-use to grow another tree. Benefits are:

- It uses over 90% less water than drip irrigation;
- It is an organic way of growing;
- The survival rate averages over 90%;
- The system creates an incredibly strong and deep penetrating root system.
- It is proven technology.

Below a selection of pictures on projects carried out by Groasis.

Figure 2-10. Regreening project in Kenya with the use of the Waterboxx®

It is clear that regreening degraded areas demands more than planting trees at random places. From a technical point of view a landscape design is required, which includes earthworks focusing on water retention and infiltration and associated civil works. The design should be embedded in an overall masterplan including financing strategies and should establish governance and stakeholder engagement focusing on strong community building. Refer to all our recommendations in Section **Fout! Verwijzingsbron niet gevonden.**.

3 Scale up assessment

In this section a strategy for regreening the northern watershed of the Sinai by RBD is described. It is important to note that this is a rough assessment and needs to be worked out on the basis of further studies, as described in the recommendations section in **Fout! Verwijzingsbron niet gevonden.**.

3.1 Scale up of Eco Oasis® production

A strong aspect of the proposed technology (using coastal sediments and seawater to recycle nutrients for terrestrial ecosystem regeneration) is the scalability of the system. TWM and the dredging company are conducting tests in a small size Eco Oasis® in the Netherlands, which has a water train consisting of six transparent cylindrical tanks with a total volume of 12 m^3. Partly based on the experience obtained in this small-scale setup, we were able to prepare a concept design for a pilot project. In this pilot project it is planned to regreen 1 km^2 in 3 years using an Eco Oasis®. The total duration of the project is 5 years, of which the first 2 years are needed to build the Eco Oasis® and revitalize the first batch of soils, trees and freshwater for planting in the desert. When this Eco Oasis® is running it will use about 170,000 m^3 of seawater (450 m^3/day) and 20,000 m^3 of sediments on a yearly basis. The rough yearly output is estimated to be 7,500 trees, accompanied with 4,000 m^3 of revitalized soils and about 500 m^3 of freshwater.

The overall objective of the pilot project is to validate and *optimize* the production of biomass, revitalized soils and freshwater. There are a couple of opportunities already identified to improve the production of the Eco Oasis®. The main opportunity is that in case a location with higher elevation (colder nights, more winds) is selected, the freshwater production can be multiplied by a factor 2 to 3, which will lead to a faster revitalizing process (quicker succession of plants in combination with more flushing). There is more that can be improved in the Eco Oasis® processes, such as (1) the aquatic decomposing process, by optimizing the diatom growth, (2) the re-mineralization process, by improving the nutrients basin designs and (3) the revitalizing process, by optimizing the soil building process and the succession and flushing process.

Also the existing precipitation can be included in the process, strengthened with fog nets which will lead to more fresh water availability. Based on the above argumentation it is concluded that the output of the Eco Oasis® could be increased with a factor 4 compared to the pilot project design. This means that for the Eco Oasis® size of the pilot project, roughly 8 hectares, 30,000 trees/ year can be produced accompanied with 16,000 m^3 of revitalized soils. However, a location is required at an elevation a 300 to 400 meters above sea level, with colder night temperatures and with the presence of more wind, because that is of essence to increase the overall production of freshwater, biomass and revitalized soils.

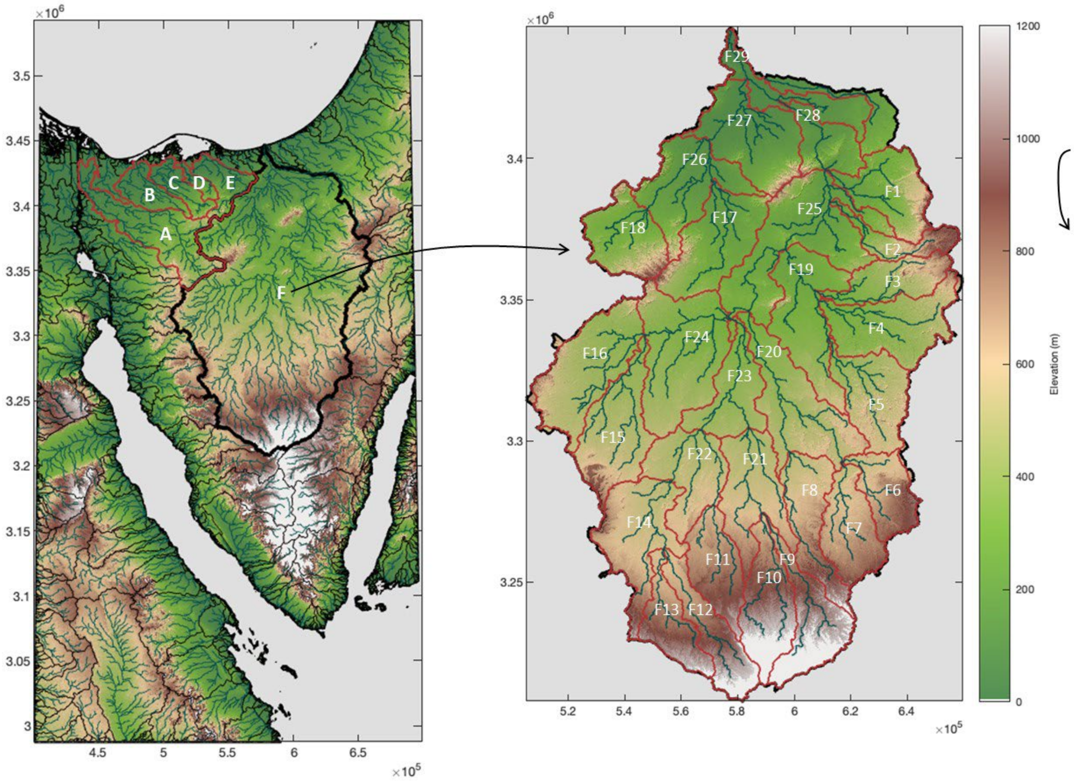
In the current assessment we focus on the required biomass output from the Eco Oasis®, which is assumed to be 40,000 trees for the regreening of one (1) km^2. This amount of trees is currently a simplified definition of ‘regreening’ and in reality polycultures should be developed of endemic species and based on the area specific climate, soil composition, geological and topographical characteristics.

3.2 Watersheds

Using publicly available topographic data[4] a model is prepared to determine the different watersheds of the northern Sinai.

The total surface area of the northern watershed subject to the assessment is estimated to be 28,500 km^2. Based on the model this area was divided in six main watersheds “A to F”. Area “A” discharges to the Suez Channel, areas “B” to “E” discharge to Lake Bardawil and area “F”, the largest one, discharges to the city of El Arish, see Figure 3-1.

[4] NASA/METI/AIST/Japan Spacesystems and U.S./Japan ASTER Science Team (2019). ASTER Global Digital Elevation Model V003 [Data set]. NASA EOSDIS Land Processes DAAC



Watershed	Surface [km²]
A	3328.36
B	1107.61
C	963.84
D	339.5
E	1102.02
F	21626.13
Total	*28467.46*

Watershed	Surface [km²]
F1	663.65
F2	307.53
F3	506.25
F4	878
F5	716.96
F6	484.27
F7	639.9
F8	661.6
F9	678.78
F10	723.09
F11	593.96
F12	594.64
F13	499.2
F14	899.91
F15	869.38
F16	1020.46
F17	884.52
F18	658
F19	919.98
F20	1020.82
F21	806.98
F22	709.28
F23	605.4
F24	1263.76
F25	1371.8
F26	834.75
F27	929.15
F28	418.18
F29	465.93
Total	*21626.13*

Figure 3-1. Main watersheds of the northern Sinai. The exact borders between the different watershed areas could be different in reality. Especially the lower plains just south of Bardawil bare quite some uncertainties due to the limited topographical differences.

Based on expert judgement it assumed that about one third (=9,500 km^2) needs to be regreened to have sufficient impact on land-atmospheric processes in order to provide sufficient precipitation in the long term. More understanding is required to determine the location dependency of land-atmospheric processes. It is also needed to understand the influence of wetlands on the energy balance and thereby on the moisture transport, this research is ongoing[5]. In the current assessment it is expected that each (sub)watershed needs to be regreened for one third of the surface area.

3.3 Strategic locations for the Eco Oasis® facilities

As explained above in paragraph 3.1, the Eco Oasis® facilities need to be placed in plain areas at an altitude of 300 to 400 m above sea level. Next to that there are preferably higher hills/mountains nearby that can be used for water harvesting with fog nets.

The most suitable location nearby Lake Bardawil which satisfies these requirements is the area called Meghara. The Meghara hillside is located south of Lake Bardawil and has an altitude of approximately 350 meters above sea level, surrounded by hills with an altitude between 500 and 750 meters. Due to the altitude the location provides a direct increase of Eco Oasis® production and it has a good potential for further passive water harvesting by the use of fog nets. The higher altitude of Meghara also makes it possible to efficiently create a fresh water baseflow that feeds the areas downstream of the pilot area for regreening.

Next to Meghara, four other strategic places are identified, see Figure 3-2. Those places are, like Meghara, on the preferred altitude. They are also situated on the intersections of the paleo river systems which provide a good water harvesting potential, but at the same time have a relative limited transport distance to Meghara.

[5] Research is on-going at WETSUS institute https://www.wetsus.nl/research-themes/natural-water-production/

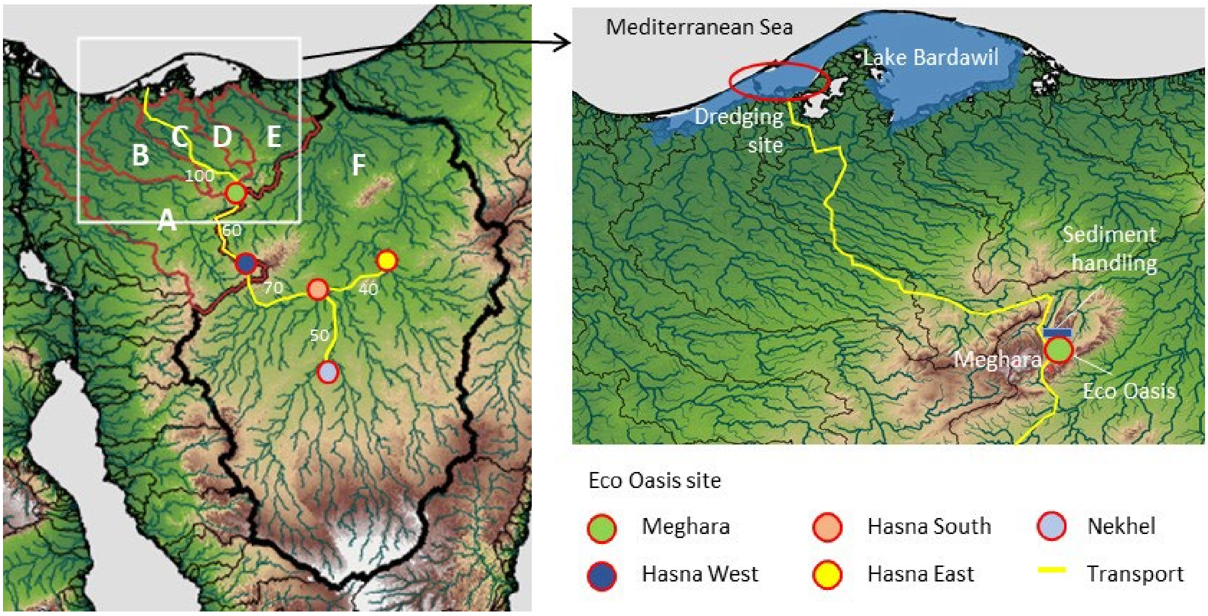


Figure 3-2. LEFT: Identified Eco Oasis® sites with good water harvesting potential and relative short transport distances. The transport lines are following the topographic contours to have limited height differences. The distances are indicated in km. RIGHT: close up of the area between Lake Bardawil and the Eco Oasis® site at Meghara.

Figure 3-2 shows that the distance between the dredging site and the proposed Eco Oasis® location at Meghara is about 100 km. The route indicated follows an existing road. The distance to 'Hasna West', further into the watershed, is about 60 km. 'Hasna South', 70km further, could become a transport hub the other two Eco Oasis® locations: 'Hasna East' and 'Nekhel'. According to satellite date, Hasna and Nekhel are both towns with road connections. It is important to limit the transport distances, because salt water and sediments are required from the shore to the Eco Oasis® facilities. This is further described in the next paragraph.

3.4 Transport

Figure 3-3 present a schematic overview of the main flows of water and sediments in the three areas of interest: the dredging site, the sediments handling + Eco Oasis® site and the regreening site

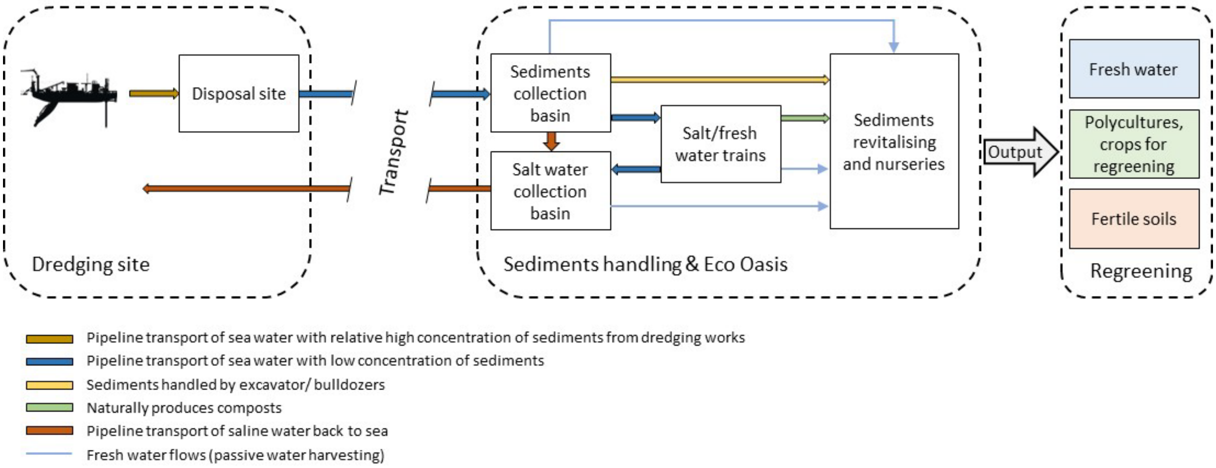


Figure 3-3. Main flows of water and sediments in the upscaling example

The processes in the flow chart are further elaborated below.

- **Dredging site**: Assuming large scale regreening, marine sediments are *hydraulically* dredged and pumped to the disposal site. The disposal site consists of settlement basins, preferable in different compartments to allow for a first segregation of the materials. Coarser material, clayish material and fines can be separated from each other by gravity and flow. This is schematized in Figure 3-4 below.

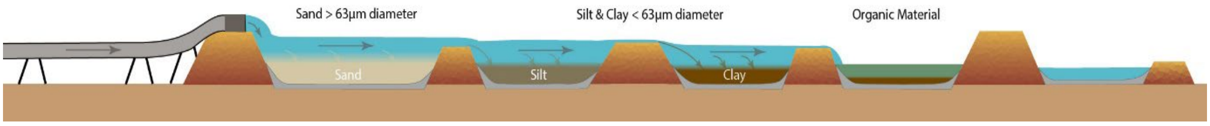


Figure 3-4. Schematization of disposal site. First step in segregation of dredged materials by natural processes.

- **Transport:** Hydraulic transport is foreseen between the disposal site and the sediment collection basin at the regreening site. Sea water with a very low concentration of sediments will be transported through pipelines. The density of the transported fluids is assumed to be in the range of 1,05 to 1,15 kg/m^3, this low density will have a relative small impact on damage to the pipes. Seawater density is in the order of 1,035 kg/m^3, so only 15 to 80 kg of fine sediments will be transported within one cubic meter of seawater. The retour flow will be sea water with almost no sediments and a slightly higher salt concentration due to evaporation and therefore in range of the incoming flow. Energy can potentially be reclaimed.

- **Sediment handling + Eco Oasis® site**: In our scale up approach sediments from the disposal site are hydraulically transported to the sediment collection basin. Salt water and sediments are used in the Eco Oasis®, as explained in Section 2.2. Surplus of salt water ends up in the salt water collection basin. Before this water flows back to the lake, the last sediments are settled in this basin and some additional evaporation will occur here and can be harvested with fog nets. This basin could potentially also be used for harvesting salt and growing Artemia.

- **Regreening site**: the output from the Eco Oasis® is freshwater, trees and liveable soils for regreening the desert. This transport is assumed to be carried out by road. Next to planting trees, large scale earth works have to be carried to reclaim natural water systems at the regreening sites. One should think of constructing terraces, swales, bunds, etc. Rough calculations show that the quantity of soils that have to be displaced is around 20,000 to 60,000 m^3/km^2.

3.5 Schedule and priority areas

For each Eco Oasis® facility the size has been determined on the basis of the required output for the regreening, refer to Table 3-1.

Table 3-1. Size of Eco Oasis® facilities based on required area of regreening and 20 years operational

	Eco Oasis®	**Total area [km^2]**	**Regreening [km^2]**	**Eco Oasis® Size [km^2]**
🟢	Meghara	5,000	1,700	9.1
🔵	Hasna West	4,200	1,400	7.5
🟠	Hasna South	7,900	2,600	13.9
🟡	Hasna East	5,800	1,900	10.1
⚪	Nekhel	5,500	1,800	9.6
	Total	*28,400*	*9,400*	*50.2*

It is foreseen that each Eco Oasis® will be operational for 20 years, meaning that the total area to be regreened is carried out in 20 years. As an example, the facilities at Meghara will regreen the sub-watersheds B to E, F18 and F26. The total surface area is about 5,000 km^2. Since one third needs to be regreened, a total area of 1700 km^2 needs to be regreened. Based on the required production a total size of the Eco Oasis® 9.1 km^2. This area is based on the required 80 hectares calculated for the pilot project. Thus the area excludes the sediment and salt water collection basins, but includes all greenhouses with salt- and freshwater trains, the revitalize sections, the sediment mixing areas, the nutrient basins, etc.

The dedicated areas subject to regreening for every facility has been presented in Figure 3-5.

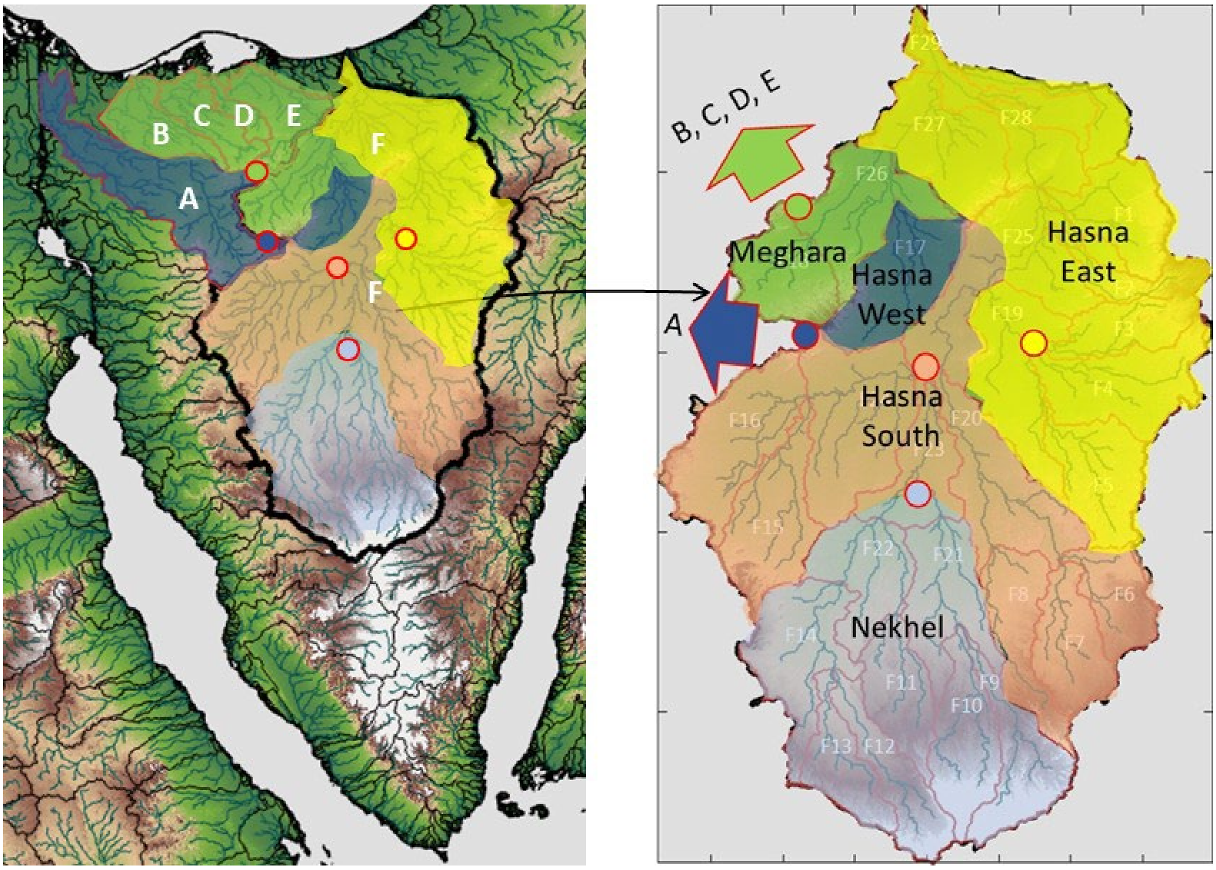


Figure 3-5. Areas subject to regreening for the specific Eco Oasis® facilities

A rough schedule has been prepared, see Figure 3-6. The pilot project will start in the first year. Parallel to the pilot project further engineering for the upscaling can take place. In 2 years, when the first results are coming in from the pilot project, the pipeline and the Eco Oasis® facilities can be constructed at Meghara.

Another 2 years further down the road and Meghara will be up and running. The pipeline construction will continue and preferably priority is given to the facilities at Hasna West and Nekhel. This to be able to regreen sub-watershed A and the higher mountainous areas F9 and F10. It could mean that after 6 years a strategic chain of sub-watersheds is regreened in order to optimally harvest the moisture provided by the wetlands at Bardawil. This is indicated with the arrow in Figure 3-6, showing the large fetch.

At year 8 all Eco Oasis® facilities are operational and about 19 million m^3 of sediments is transported into the northern watershed on a yearly bases. After 23 years the production could be reduced and after almost 30 years 9,400 km^2 is regreened by the RBD methodology and based on the assumptions as stipulated in this report.

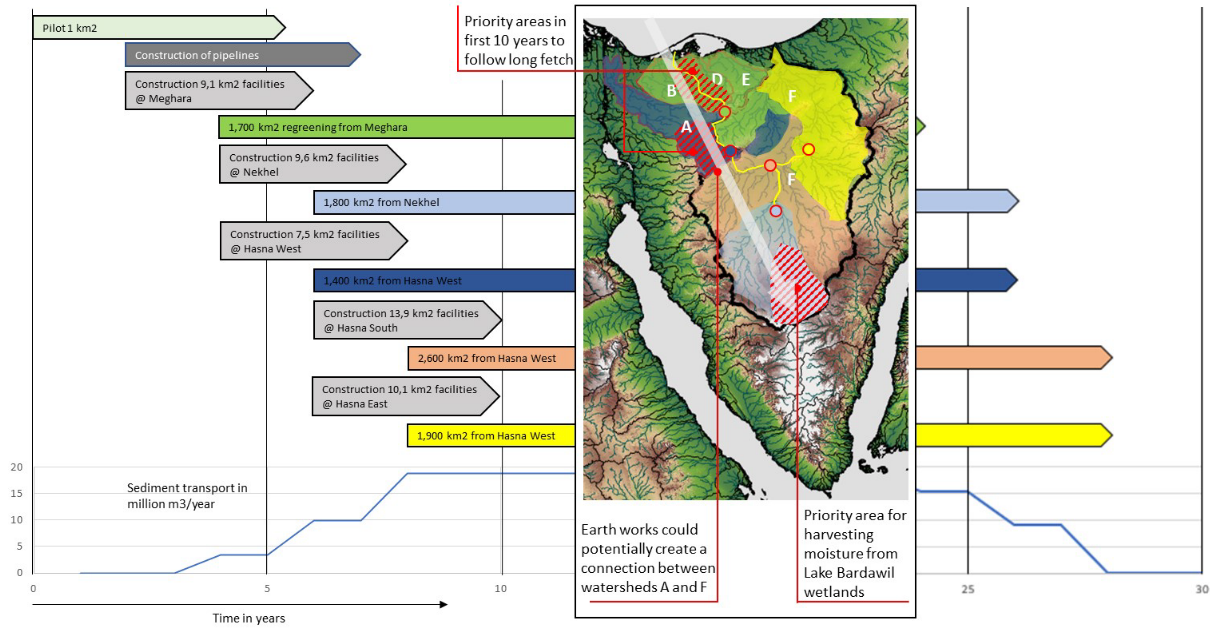


Figure 3-6. Rough timeline for regreening the northern watershed of the Sinai

3.6 Costs and benefits

Based on the plan of approach described in the previous paragraph, a (very) high level cost estimate has been prepared, see Table 3-2.

Table 3-2. High level cost estimate for regreening 9,400 km² in the Sinai desert using RBD over a period of 20 years

Item	billion €
Dredging & disposal of 400 Mm3 of fine sediments	1.5 – 2
Transport of water & sediments	7 – 9
Sediment handling and Eco Oasis® facilities:	8.5 – 11
Transport and planting of 40 M trees with 20 Mm³ sediments:	2 – 2.5
Earth works and civil works at regreening site:	2 – 2.5
Investigations, engineering, financing, governance, stakeholder engagement	10 – 12
Total sum	31 – 39

Total costs for regreening 9,400 km² are in the order of 31 to 39 billion euro, this is 3.30 to 4.15 €/m². The benefits are numerous. A regenerated ecosystem instead of a desert will create a huge amount of social and economic benefits for local communities: increasing food, fresh water, jobs, peaceful lives and a sustainable future. It touches almost all UN Sustainable Development Goals (SDG).

3.7 Market potential

The ability to manage at a landscape scale will ultimately decide the future of land resources – soil, water, and biodiversity – and determine the rate of success in delivering poverty reduction, food and water security, and global cooling.

As we focus on deserts in general and the Sinai in particular, our immediate attention goes to the Middle East and North Africa (MENA Region).

The principle of Resource Based Dredging is founded on the fact that rivers deposit organic rich sediments through their lifetime. It is important to realize that the Sahara experienced several humid episodes, associated with the development of vast fluvial networks and enhanced freshwater delivery to the surrounding ocean margins. There are several studies indicating that 10.000 years ago the North African Sahara desert was green with humid climates, lakes and rivers. One example is presented in Figure 3-7.

Figure 3-7. Map of the Saharan mega-lakes of the Holocene Wet Phase shows what the northern part of the African continent might have looked like when it was far from the desert it is today (c. 3000-7000 BCE). As the map suggests, it was covered in grassland and dotted with shallow lakes. Ancient humans used its waterways to travel up through Africa. Its legacy remains today in rock art and dried riverbeds (Drake et al., 2016)

The ''business'' of WWER will ultimately be one of the most meaningful developments there is on earth. The United Nations have declared the current time as the "decade on ecosystem restoration". The time to move is now.

3.8 Conclusions & recommendations

3.8.1 Conclusion

A high-level estimation was made for regreening 9,400 km^2 of highly degraded land over a period of 25 to 30 years applying Resource Based Dredging. A total of about 380 million m^3 of dredged sediments is required to use as input for the large-scale Eco Oasis® facilities (50 km^2). The preferred locations for the Eco Oasis® are at five sites in the watershed, having both climatic benefits to boost water harvesting and topographic benefits to make optimal use of natural precipitation and water flows in the landscape.

By using pipelines to transport the -in seawater suspended- sediments, sufficient salt water will be available for all processes within the Eco Oasis®. The total costs for regenerating 9,400 km^2 of desert is roughly estimated to be in the order of 31 to 39 billion euro.

Note that actual regreening would go hand in hand with development of agriculture (and thus crop production, jobs, etc.). It is expected that the current Eco Oasis® output numbers are very conservative and can potentially regenerate a much larger desert area than the numbers show, taking full advantages of all possible positive feedback loops.

3.8.2 Recommendations

The main recommendation is to secure and execute the pilot project to validate the main technical and practical aspects of Resource Based Dredging in general and the processes used in the Eco Oasis® in particular. It is expected that a successful pilot project will pave the way to large scale implementation of Resource Based Dredging.

In parallel to the above it is recommended to carry out a broader feasibility study to further validate the economic viability and financeability of regreening the Sinai with Resource Based Dredging. We foresee the following main steps:

1. Background & site selection study, includes mapping of strategic location on the bases of several criteria (not limited to):
   - Soil type, climatic and topographic characteristics (refer to Figure 3-8);
   - Strategic land use change locations[6];
   - The costs of transport and ease of access (presents of infrastructure, safety, permits, etc.).
2. Inception study, including
   - Economic & social case of concept "why would governments and development financers invest?"
   - Engage strategic partners and build strong relationships;
   - Environmental & Social Impact Assessment;
3. Prepare business models and market sounding:
   - What are the green and red flags, what is the appetite of financers?
   - Identify the adequate financial instruments to be deployed over time;
4. The project business case:
   - The Project FEED;
   - Financeability and risk mitigation strategies;
   - Organisation, stakeholder engagement and governance;
   - Setup procurement and contractual frameworks;
5. Implementation strategy.

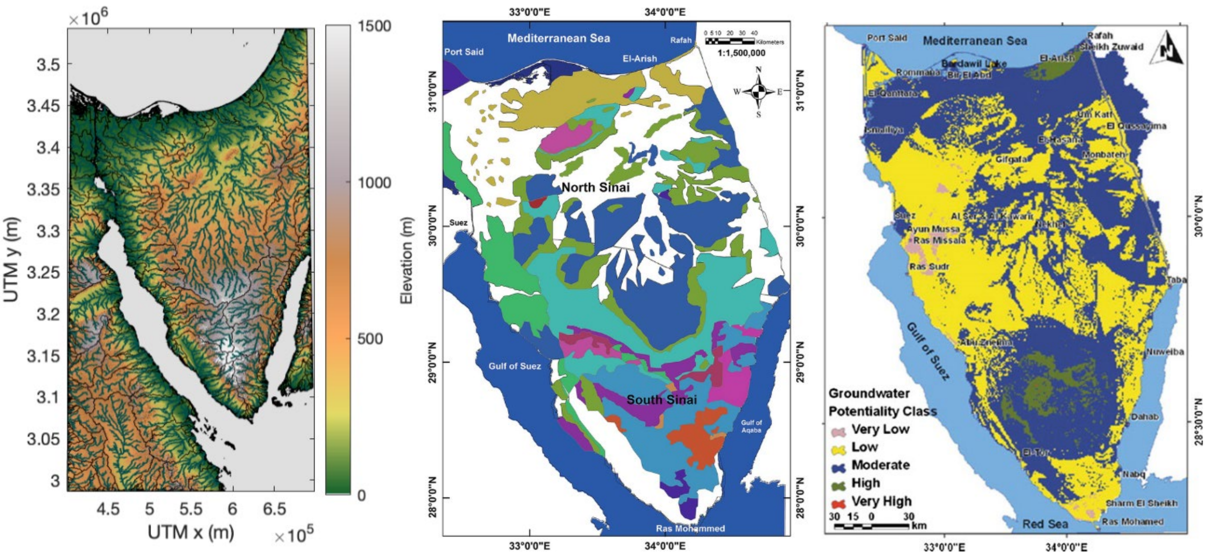


Figure 3-8. Some criteria for site selection, from left to right, main and sub watersheds (TWM), geological formation (Omran 2017) and groundwater potentiality (Elbeih 2014)

[6] For this aspect WETSUS research is starting up and will address (1) the hydrological processes in the watershed (e.g. turbulent fluxes of sensible and latent heat, land-surface temperature and evapotranspiration, streamflow and infiltration rate) and (2) the impacts of land use change and afforestation on coupled water and energy fluxes in the watershed (especially on spatial land-surface temperature and evapotranspiration patterns)

DISCLAIMER