other leisure activities. Given the park's layout and multifunctionality, the term "wastewater treatment plant" could be replaced by the much more accurate "water reclamation park."

Because Koh Phi Phi is a small island located in a national park and is highly dependent on the tourism industry, the maintenance of crystal-clear water at the beaches is essential. Therefore, it would be detrimental to discharge wastewater onto or near the beaches. Rather, the wastewater had to be regarded a resource to be re-used for irrigation purposes. This would be a benefit for the tourist-related businesses relying on green lawns, blooming flowers, and lush trees, especially because the reclaimed water could be sold at a fraction of the cost of tap water. This would benefit the environment and the island community as a whole by counteracting the water scarcity problem.

6.1.3 Design: An Integrated Cluster Wastewater Management System

The final design included all components of wastewater management: wastewater collection, treatment, urban integration, re-use, energy, and organization and financing of the O&M (Fig. 6-7). The project was built and today operates as follows.

Almost all of the wastewater from washing, bathing, and cooking (the greywater) is discharged to a closed-loop collection system, separate from rainwater. Some, however, is discharged to semi-open drains before being connected to the closed-loop, small-pipe system. Most hotels and restaurants have installed grease traps within each compound to prevent oil and greasy wastes from clogging the collection system as well as the municipal treatment facility. However, some of them—especially those coming into operation late in the project or after project completion—have still (as of mid-2009) not installed oil and grease traps. The wastewater from toilets is collected and pretreated in local septic tanks. The effluent from the septic tanks is discharged either to the closed-loop, small-pipe system or to the semi-open drains that collect the greywater from households.

In the areas where the closed-loop, separate collection system is installed, this system receives and transports only domestic wastewater. Stormwater run-off is managed with an independent drainage system. This way, the risk of sanitary wastewater reaching the streets during heavy showers is minimized and sand is prevented from entering and blocking the pipes, which ensures functionality and minimizes the maintenance costs of the system. Moreover, the wastewater is not subjected to dilution, which ensures a relatively constant level of treatable constituents and optimizes the design criteria for the wastewater treatment facility.

Figure 6-7. The constructed wetlands on Koh Phi Phi 2 months after completion, November 2006.

Because there is no law forcing households to connect to public wastewater collection systems, the team decided that construction of the collection area of the project would include connection of households located there. This meant that the construction contract included service pipes and actual connection taps for households that needed and wanted to connect. The contract also included a number of septic tanks and oil and grease traps for households, restaurants, and hotels that were willing to install them to enhance the efficiency of the system.

All wastewater is collected by gravity flow and, because oils, greases, and solids are less likely to reach the local treatment units, the system is unlikely to clog. The gravity-flow system collects all domestic wastewater to a single location in the central part of town, from where it is pumped to the treatment facility (Fig. 6-8). To prevent odor problems, the pumping station is equipped with an odor control unit.

Technically, the treatment facility can treat up to 400 m^3 of wastewater every day, which is treated by a mix-and-match of four different treatment technologies. As the wastewater flows through the treatment facility, it passes through a vertical subsurface-flow constructed wetland, a horizontal subsurface-flow constructed wetland, a free-water surface-flow constructed wetland, and a pond. The vertical gravel filter treats the wastewater by removing 80% to 90% of the organics, nutrients, and pathogens from the wastewater. From the vertical-flow wetlands, the water flows into a series of, first, hori-

Figure 6-8. Images from the process. Three-dimensional illustration used for public hearings and decision makers (*top left*); the mayor's technical supervisor, Mr. Pisit Srivilairit, and the contractor, Mr. Niras Limprayoonyong of Mahaporn Co. Ltd. (*bottom left*); and two international consultants, Dr. Hans Brix (*left*) and Mr. Carsten H. Laugesen doing on-site inspection (*bottom right*).

zontal subsurface-flow wetlands, and then surface-flow constructed wetlands, and finally into a polishing pond before it is discharged to the re-use reservoir. These components are all very simple and require almost no maintenance.

To reduce energy consumption in the collection system and the water reclamation park, the pumping station in the town center is equipped with solar panels to provide electricity to operate the pumps. The solar power station was designed to operate one pump for 6 hours each day. The treatment facility intake is dosed using a siphon instead of an electrical pump, which reduces the system's energy consumption because the siphon works entirely on hydraulic principles and without a power supply.

The reclaimed water and flowers from the wetland units are sold to private landowners and the revenue is designated to cover some of the O&M costs. This supports the long-term functionality and appearance of the wastewater treatment system. By generating income from its operation, the facility

has a better chance of becoming a sustainable component in the island's infrastructure.

A local contractor, Mr. Niras Limprayoonyong of Mahaporn Co. Ltd., built the project, and he hired members of the local community committee as advisors and middle managers. This imparted knowledge of the local context, local suppliers and local pricing, and loyalty and mutual responsibility. This also developed local expertise on the functionality of the system, the facilities, and individual installations—all important issues for the O&M of the system in the years to come.

After construction was completed, an environmental fund managed by a local environmental committee was established to secure the ongoing O&M of the facility. The fund would receive money from the 5-year O&M contract signed with the donor, from the sale of flowers and re-used wastewater, and from wastewater connection fees for new businesses and hotels that connect to the system. All this income is to be spent on O&M (staff, power supply, etc.) and promotional activities. The committee consists of the mayor and members of the local community.

The project has become a showpiece of integrated cluster wastewater management. It not only meets the demand for urgent rehabilitation of the wastewater infrastructure on the island, but also addresses the island's specific limitations on water and energy supply as well as the need for cyclic management and self-reliance on an island with limited natural resources. The project represents the essence of what we consider appropriate and sustainable cluster wastewater management, as the integrated system on Koh Phi Phi has attempted to apply these principles in practice.

6.2 Reflections on Appropriateness and Sustainability

The six-element checklist indicates, first, whether all elements in the wastewater management system have been dealt with, and second, roughly to what extent each element is considered to fit the local setting (Fig. 6-9). As can be seen, the Koh Phi Phi system does contain all six elements in the management system and scores high on four of them.

6.2.1 The Existence of Real Needs—It Makes Sense!

The reasons why wastewater at Koh Phi Phi should be collected and treated are obvious to almost all landowners, residents, and tourists on the island. The case certainly would pass the "does it make sense" test. Without wastewater treatment, the tourist industry would quickly and visibly be negatively

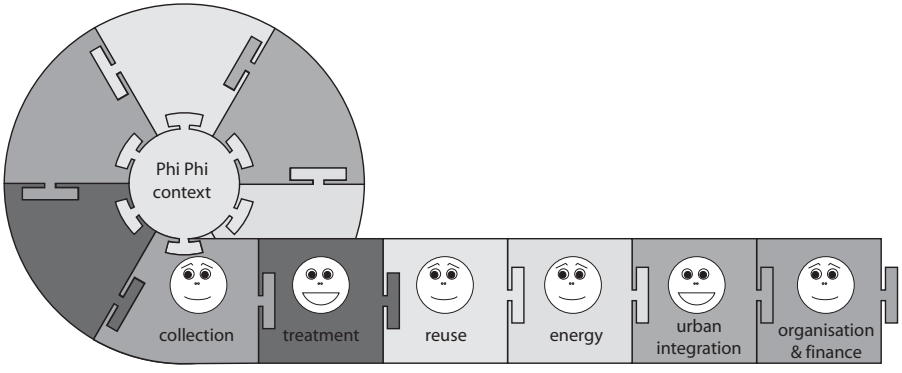

Figure 6-9. Contextual appropriateness scoring of the six elements of the wastewater management system at Koh Phi Phi.

Smile, contextually appropriate; no expression, somewhat appropriate; frown, not appropriate.

affected. Wastewater discharged directly to the beaches, wastewater overflowing from seepage tanks into the streets and onto the ground, and toilets that cannot flush are not many tourists' image of a small tropical paradise island. Without a centralized collection system, many of the households will have problems getting rid of their wastewater because local groundwater levels are periodically too high, and land parcels are too small for full seepage systems to be relocated (which is the traditional way of emptying septic tanks: relocate it 2 m away!). This means most of the influential landowners and many of the smaller households have a direct and objective interest in the island having a well-functioning wastewater management system in place.

Other contextual needs on Koh Phi Phi are typical island issues of scarcity. The first is water scarcity. Water supply depends on seasonal levels of precipitation, and the island often experiences periods of insufficient water supply. Most of the water supply is private and very expensive, so water becoming wastewater is a luxury. A wastewater management system that could return some of this water, at a lower cost, would be highly desirable.

Next is land scarcity. With only the middle low-lying strip of approximately 30 ha (0.3 km^2) being available for private or communal ownership (the hills are all protected national parks), and with more than 1 million tourists visiting the island yearly, land is scarce and valuable. Providing a 6,000-m^2 central wastewater treatment facility on the only tract of municipal land on the island, thereby reducing land requirements for private wastewater treatment, is therefore appreciated by the private landowners.

Finally, there is energy scarcity. The island is located about 40 km from the mainland and all electricity is currently supplied by private diesel generators,

which are expensive, noisy, and annoying to residents and visitors. Providing a wastewater management system with low energy needs at least does not aggravate the energy supply situation.

6.2.2 Taking Local Issues and Stories Seriously

At the first meetings between the mayor and the design team, the mayor emphasized three requirements that he and the local citizens considered most important:

- The new system should not smell bad.
- It should look beautiful.
- It should be easy and cheap to operate and maintain.

All these requirements were closely linked to previous and existing issues and stories on the island. For example, residents and hotel owners had rejected the previous wastewater collection and stabilization pond system, mainly due to its odor problems. As a consequence, the system was ultimately shut down and the ponds turned into unsightly stormwater-filled ponds. This experience had taught local residents, landowners, and the municipality that a wastewater treatment plant located adjacent to dwellings can be a nuisance to its neighbors.

Given this history, no one (and especially not the mayor) wanted to risk reintroducing problems connected to stagnant, smelly wastewater if the wastewater treatment facility was to be rehabilitated. This created an unequivocal demand for an odor control system in all components of the system—in the collection system, at the pumping station, and at the constructed wetlands. If the odor control system were to fail, public support would fail and the project as a whole, and the mayor in particular, would come under pressure.

Beautification and easy and cheap operation were the two other important local issues, which from a design point of view simultaneously become constraints and opportunities. Both issues are dealt with in the following sections.

Apart from these three paramount issues, a long list of other local constraints and opportunities had to be taken into account, such as the existing infrastructure, the mayor's preferences, the available budget (a low-budget donor project), the location, and the landscape.

6.2.3 Creating as Many Win-Win Situations as Possible

The winner in wastewater treatment is often thought of as the environment, but this is rarely sufficient. Win-win situations have to be sought, found, and created for as many stakeholders as possible. Even though motivations are often personal and hidden, and therefore not so easy to predict or get right,

some of the positive motivations—win-win situations—established on Koh Phi Phi include:

- *The mayor.* Who knows what a mayor gets out of such a project? But one thing is certain: If Mr. Kittitarakhun had not gotten anything, the project would not have happened and this chapter would not have been written. He was the key person in this case, and this is probably more or less the truth of island municipalities. Reputation, personal motivations, an honest wish to get things done better—the motivations might be many and interlinked. Interestingly, long before the tsunami disaster, Mr. Kittitarakhun had on his own investigated the possibilities for constructed wetlands on the island. This project provided him with a chance to capitalize on this interest and to create a showcase, a first, in Thailand.
- *The contractor.* Besides the opportunity to make some money, this project offered Mahaporn Co. Ltd. a strategic opportunity to establish itself in a possible new market. Mr. Limprayoonyong had a previous close connection to the mayor and considerable working experience on the island. In fact, before the construction was finalized on this project, he had secured two contracts with another municipality and a large industrial estate to design and build constructed wetlands for wastewater treatment.
- *The key hotel and landowner.* Because of this successful collaborative project, Ms. Jantharo did not have to rehabilitate her damaged advanced wastewater treatment plant and could avoid this considerable cost by linking to the new municipal treatment plant.
- *The local community leader.* Mr. Sommai was hired by the contractor as construction supervisor and was later put in charge of O&M of the system.
- *The local residents.* They were relieved of the increasingly difficult problem of finding new locations for their seepage systems.
- *The international and local consultants.* We were given the chance to work together with a group of honest, hardworking people (the mayor, the contractor, the local community leader) who not only wanted the project, but also wanted to implement it to a high standard. We were able to design, innovate, and bring to full implementation an interesting project within our professional field of interest—and hopefully the design was something to be proud of. Such a chance does not happen every day in the wastewater management sector.
- *The others.* The governor, the Ministry of Natural Resources and Environment, the Wastewater Management Authority, the National and Provincial Public Works Departments, the Danish government

as the donor, the participating universities and consultants, the subsuppliers, the gravel freight company—the players involved in the design, approvals, tendering, contracting, and implementation were diverse and numerous. A key factor for success and sustainability, and probably the most important task for the project manager, was that at the end of the day all of these involved actors had a win-win feeling.

However, the other side of this coin is that the involved parties have something at stake—if the system fails, those involved will lose face, which is an extremely strong motivator. We will lose face if we have guaranteed to our peers, constituents, supervisors, or bosses that the project will work. The issue here was to develop as many interdependent relationships as possible: the contractor dependent on the mayor; the mayor accountable to the governor and his voters; the consultants dependent on their reputation in the international professional wastewater field; the community leader responsible to the powerful landowners on the island; and so on.

Exposure is important in this respect. A system that was built and failed in a small municipality in the middle of nowhere would attract little attention. But a system having such exceptional design and landscaping, which has been given exposure in newspapers and professional magazines, which weekly has groups of visitors from the Ministry, from abroad, from NGOs, and from technical experts from all over, would be more difficult to let fail. It could still fail, but this is less likely because so many people have something at stake and could lose face.

6.2.4 How Could This System Fail?

With the completion of the construction, a good foundation for efficient wastewater management on Koh Phi Phi is in place. The system is contextually designed; it is appropriate; it makes sense. But it must be stressed that it is a *design*—a design that has just been implemented and set in operation. If the system runs into serious O&M problems, or even fails, a number of possible reasons exist.

The system is up against a historically poor track record in Thailand, on islands, and in particular on Koh Phi Phi. When reflecting on sustainability, it might sometimes be good to think of the big picture. What is the system up against? This means that sustainability is not seen in the singularity of an individual project, but in the multiplicity and complexity of a historical, political, and national perspective.

Wastewater management systems in Thailand have a troubled history—almost all of them malfunction soon after implementation. On islands, such systems are up against what could be called the "island culture of small com-

munities," with shifting strong and weak community leaders and organizations and high levels of corruption and infighting. Koh Phi Phi, in particular, has a long history of malfunctioning, inoperative, and unmaintained infrastructure projects—wastewater as well as energy supply, water supply, and solid waste management.

Integrated constructed wetland systems, in particular, are up against lack of long-term historical experience. These systems are up against a general and relative lack of technical and practical applied experience within the field. This is especially true for vertical subsurface-flow constructed wetlands. For these systems we do not have 30 to 40 years of practical, applied O&M experience to rely upon, as is the case for conventional technical options. On a more practical level, such systems are up against some specific O&M issues relating to uncertain loading rates, lack of experienced staff, technical unknowns regarding the solar-powered pumps, the vertical-flow siphon-powered distribution system, and so forth.

Technically, the designed system is risky because it entails elements not too many local people have experience with, such as siphons and solar-powered pumps. But these are calculated risks because backup systems were provided for the technical components that might run into O&M problems. Our approach for the technically riskier components was that they were important to include because they contributed to the general development within the wastewater management field. But also, that they were included in such a way that if these experiments did not work, the wastewater system as a whole would not break down.

Two specific potential weaknesses are the less-than-full coverage of both the separated collection system and the oil and grease traps. These two important issues for functionality were only partly dealt with during the construction of the system, and this might result in future O&M problems if not dealt with systematically and effectively.

Why were they only partially addressed? The hotel owner did not want to allow the conversion of the semi-covered collection system in her area, the restaurant owners did not want to have to install oil and grease traps in their kitchens, and there were no municipal by-laws to force this through. All these valid and factual reasons proved very difficult to deal with.

To these could be added the issues of construction fatigue and the normal tendency to take the seemingly easy or trivial route. Designing and constructing such a wastewater management system—in a highly complex political setting with competing national political factions that wanted to be in charge of the tsunami reconstruction funds, and competing national, provincial and municipal actors, and a donor-financed municipal infrastructure, using an innovative approach requiring lengthy discussions and negotiations, on an island located 40 km from the mainland which required all materials,

gravel, equipment, and staff to be ferried to the island and remain on the island for more than one year—was an extremely time- and energy-consuming task. Toward the end of such an endeavor, construction fatigue typically sets in. Managers and workers want to finish the work and move on. This can lead to lack of energy to solve some of the trickier issues, especially the ones not purely technical but nevertheless linked to people, discussions, and long negotiations—like convincing the restaurant owners that they should make the effort to have their kitchen retrofitted with oil and grease traps.

Issues that might seem less complex or technical and therefore more trivial (e.g., oil and grease traps) are in fact often the most difficult and time-consuming, and construction projects should probably begin with them. This is especially true in the context of "construction fatigue." The Koh Phi Phi project started out with the most interesting and technically challenging element for all involved, the construction of the flower and the butterfly. The construction of and adjustments to the collection system were left to the very end. To leave the boring elements until later might be human nature but, in hindsight, is not always the best solution. However, this wastewater management system was not just built and then left to the municipality. A number of postconstruction safeguards were put in place.

Post-experiences: difficulties in motivating the municipality and activating the safeguards. It is only to be expected that wastewater management facilities will experience a number of O&M problems during their first year of operation. Some of these originate from the construction itself, and some from the always necessary adjustments and operational run-in period, especially a biological and innovative treatment facility like the one established on Koh Phi Phi. Because it was anticipated that close follow-up and adjustments would be required, five key safeguards for the first year of operation of the system were established.

1. A performance bond of 10% of the construction cost was provided by the contractor, which enabled the municipality and the donor to require the contractor to rectify, within the first year, any construction mistakes and/or omissions discovered.
2. A 3-year postsupervision contract was signed with a local expert to closely follow and supervise the technical O&M issues that would arise, and report these to the municipality and the donor for action to be taken immediately to ensure proper and efficient operation of the system.
3. As an integrated part of the total construction budget, a 5-year, 2.5 million baht ($79,000 USD) O&M budget was provided to the municipality, with bi-yearly installments of 250,000 baht ($7,900 USD). The purpose of this budget was to provide additional finan-