Design Issues in Farmer-Managed Irrigation Systems

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Design for Participation: Elephant Ears, Crocodile Teeth and Variable Crest Weirs in Northeast Thailand

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THE CONTEXT OF IRRIGATION DEVELOPMENT IN NORTHEAST THAILAND

* Undulating topography
* Unreliable rainfall
* Stormflow irrigation
* Earth weirs
* Episodic mobilization

Farmers in northeast Thailand have developed a system of people's irrigation adapted to local social and environmental conditions, including unreliable rainfall, flat to undulating topography, sandy soils, and a farming system centered on the cultivation of glutinous rice. Villagers primarily rely on episodic mobilization for the creation and maintenance of collective goods such as irrigation weirs. These have formed the context within which local people have developed irrigation.

The primary crop in northeast Thailand is glutinous rice. Households grow one rice crop a year, relying primarily on rainfall. Upland crops such as cassava, corn, and kenaf are important

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sources of income. Rainfall ranges in different parts of the northeast from 800 to 1,800 millimeters per year. Rainfall in northeast Thailand is quite uncertain, especially in the first months of the rainy season from May to July. Dry spells frequently damage rice crops.

Most of the topography ranges from flat to gently undulating. Almost all streams stop flowing during the dry season. Wet-season flows are often very low between storms.

The key irrigation task is to divert storm runoff flows from streams. Villagers build and rebuild earth weirs to divert water to rice fields during the wet season. Earth weirs are also used to store water in the stream bed and adjoining aquifer for use during the long dry season. The need for water for livestock, fishing, domestic use, and dry-season gardening expands the pool of beneficiaries beyond just those whose rice fields can be irrigated.

Weirs are built by individual households, groups of people with neighboring fields, or village efforts. Episodic mobilization to build or rebuild weirs is the principal activity. There is little or no formally organized routine operation or maintenance activity. Instead, when a need arises an informal committee of senior villagers takes the initiative in consulting other villagers, deciding what needs to be done, mobilizing money and labor, and scheduling and supervising construction or repair of weirs.

Sandy soils are quite prone to erosion. The gentle slopes and the absence of rocks means that streams are not confined to a single channel location. The earth weirs traditionally built by villagers easily wash out or the stream may simply shift to go around the weir.

Weirs irrigate adjoining fields. Water is often diverted directly from the stream into the fields without canals. Natural and constructed levees along the stream help to control water flows. Gentle slopes reduce the potential for distributing irrigation water over wide areas, constraining the potential for developing irrigation. Reliance on storm flows places a premium on moving as much water into fields as quickly as possible before flows drop below the levels at which irrigation is possible.

Together, these natural conditions create a quite different environment for irrigation from the hilly areas where most studies of locally managed irrigation have been carried out. In northeast Thailand the principal irrigation activity has been the episodic construction and reconstruction of earth weirs in order to divert storm runoff flows.

As outside resources became available attempts were made to replace earth weirs with permanent concrete structures. In 1975 and 1976 funds were made available to subdistrict councils to spend on rural public works. Many small weirs were built under this program. Many other agencies also funded the construction of small weirs and reservoirs. During the late seventies the Royal Irrigation Department (RID) also began construction of many small weirs and reservoirs.

The results of such intervention were often disappointing. Many structures failed often during the first year of use. Streams washed around some structures, leaving them sitting on abandoned stream channels. Others had little capacity to divert or store water, especially in comparison to the amount invested in them.[1] This experience made it clear that simply providing funding was not enough to lead to successful development of weirs.

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[1] See Asian Institute of Technology 1978 for an assessment of water-resources development in Thailand. This study helped to set the framework for much subsequent government investment. Unfortunately, many of the criticisms still hold true.

HISTORY OF THE PROJECT

The Khon Kaen University-New Zealand (KKU-NZ) Small-Scale Water Resources Development Project began in 1978 with the goal of helping water-resources development in northeast Thailand. It came to focus on construction of weirs because it was an area in which there was a need, and one in which civil engineering skills were required.[†]

During the first years of the project much time was spent on observing earlier water-resource projects in order to try to identify the reasons for their failures. The first project engineer, Brian Warboys, visited many sites of failed weirs and talked with villagers about what had happened.

Based on an analysis of previous experience a new design was developed, intended to be low cost and easily built by local people and to avoid the problems which often occurred in earlier weirs. The goal the project set was to design a weir which could be built for less than US$5,000. The first structures were built by the Khon Kaen University (KKU) students who during their holidays went to help villagers. Subsequently, New Zealand government funding was obtained to build more structures. A KKU technician, Prasert Termsak, played a major role in communicating with farmers and supervising construction.

The performance of these new structures was followed up through repeated visits to the sites after the weirs had been built. Based on experience, the design and planning processes were revised and improved. Being in a small, independent project meant there was plenty of room for experimentation and learning. The approach used was very consistent with a learning-process approach to development (D. Korten 1980; Johnston and Clark 1982; F. Korten 1986).

Through 1985 over 50 small weirs and reservoirs were built, most using variations on the design principles which are discussed in this paper. A standard design was developed, and presented in a construction manual.

The use of the design and approach has since been spread by the People's Volunteer Weir Project of the Department of Local Administration, Ministry of Interior. Aspects of the design have also been used in the Job Creation Program and other interventions to develop irrigation in northeast Thailand. Hundreds of such weirs have already been built and many more are planned.

During 1985 and 1986 an evaluation was carried out which included visits to all the sites of weirs built by the project in the Khon Kaen province (Tantuvanit, Bruns, and Angsuwotai 1986).[††] At three sites case studies for the evaluation were conducted by research assistants who lived in the nearest village for about three months. For the survey part of the evaluation all weir sites were visited and basic information collected and for half of the sites more detailed interviews were carried out.

Forty-five of the 50 weirs built by the project were still in operation. Two of the failures were connected with attempts to add to existing structures and were probably due to faults in the older

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[†] For a good discussion of the project and design as of 1983 by the second of the two New Zealand Project engineers, see Mayson 1984.

[††] Along with participating in the evaluation, during this period and afterwards the author studied an area in northern Khon Kaen which has seven KKU-NZ weirs.

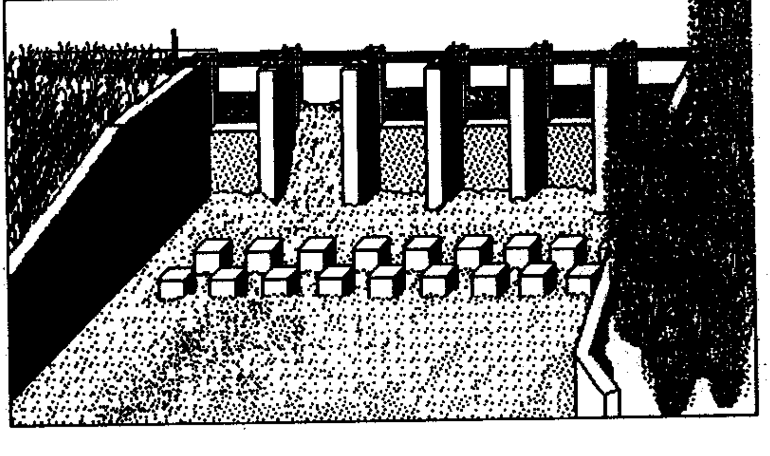
structures. Another weir was very poorly located, with the stream curving toward the weir from the side rather than coming straight on, and the stream eroded through the earth embankment next to the weir. Another weir was used as a spillway for a small reservoir with a very small catchment. It failed when the area below the spillway was flooded killing the grass which had previously stabilized the soil on the infrequent occasions when the spillway overflowed. The fifth weir seems to have been too narrow and not tall enough for the site so the stream washed around it despite repeated attempts by farmers to repair flood damage. After the evaluation in 1985 at least one more weir is known to have failed due to heavy sedimentation upstream of the weir, and because the weir was much narrower than the stream channel in contravention of the design guidelines.

The evaluation found that 90 percent of the weirs were still in operation and most were providing substantial benefits. In general, villagers were operating and maintaining the weirs on their own. Weirs were used for irrigation of rice and other crops, water for livestock and domestic use, and for fishing. An economic analysis suggested that for most sites, benefits substantially exceeded costs. In several cases the KKU-NZ weirs were located downstream of larger weirs built by the Royal Irrigation Department (RID). The KKU-NZ weirs provided similar or greater benefits for less than a tenth of the cost of the larger RID structures.

THE DESIGN

The variable crest is a key part of the innovative design developed by the KKU-NZ Project. Other elements of the design include sizing the structure according to the size of the streambed, routing flood flows through adjoining fields, and using simple standard dimensions, vertical sidewalls, wingwalls (elephant ears) and stilling blocks (crocodile teeth). Figure 1 illustrates a KKU-NZ weir. The standard design can be used on streams up to 20 meters (m) wide and up to 3.5 in depth.

Figure 1. Illustration of a KKU-NZ weir.



The use of stoplogs in the design means that boards can be put in the structure to raise the crest level so that it may be possible to divert water into fields even during periods of moderate or low flow. During periods of high flow the boards can be removed to pass large flows downstream, something which cannot be done with earth weirs. During the dry season two layers of boards can be put in and the area between sealed with mud in order to store water.

The width and height of weirs are set according to the dimensions of the existing channel. The standard design can be up to 20 meters wide and can have fixed crest heights of 1, 1.5, or 2 meters. The fixed crest is set to block at most 60 percent of the cross sectional area of the channel. The weir is designed so that it can pass the same maximum flow as the existing channel, albeit at a higher velocity, allowed by the use of a concrete structure. It is assumed that excess water will flow through adjoining fields just as it does already. Relatively flat topography and mono-cropping of rice on low-lying areas mean that there is usually little damage from such flooding.

This approach to design contrasts with usual design techniques which require some sort of estimation of maximum flows, after which the structure is designed to be able to accommodate the largest flood which could occur every 20 years, or some other assumed return period. Sizing according to the existing channel avoids the need for a survey or records of earlier stream flows. This approach leads to much smaller and cheaper structures compared to the Royal Irrigation Department's designs which are often more than twice as wide and ten times or more as expensive. It leads to much more effective structures than those built under the Job Creation Program and other programs which fund small weirs with costs similar to the KKU-NZ weirs.

The goal was to develop a design which could be built for a total materials' cost of less than US$5,000. During the project the cost of construction materials was about US$400 per meter of width of the weir. The average width was about 8 meters. Costs have risen since. As a consequence of inflation and of construction of weirs through a government program, costs have risen up to twice as much per meter of width, compared to when the weir was built as part of a small university-based research project.

As part of the project's effort to produce a low-cost design, safety factors were set according to the needs of the design. These include construction using unskilled local labor. However, the weirs are built in relatively flat areas. When flooding occurs, water levels rise gradually so that the water level of the downstream side of the weir also rises reducing stress on the weir. The weirs are located on streams and do not usually hold back large volumes of water compared to reservoirs. The evaluation found that storage in the stream channel averaged only 5,000-10,000 cubic meters per site. As a result of these conditions, failure of the weir may cause some damage to fields but does not represent a major hazard to life or property. Therefore, the design can assume a higher level of risk than larger structures for which a more conservative approach to design is appropriate. Accepting higher levels of risk leads to substantial reductions in costs of construction.

Wayland (1987) carried out a structural analysis of the design which found that in general it was sound though safety factors for some aspects were low compared to more conventional design standards. He made several suggestions for strengthening it. The analysis was consistent with evaluation of completed structures in the field which did not find major structural problems. None of the weir failures seem to have been related to structural problems in the design.

Guidelines for designing and building the weirs have been provided in a manual prepared by the Water Resources and Environment Institute of the Khon Kaen University Faculty of Engineering (Khon Kaen University 1986). Weir operation was examined by J.R. Rinfret (1985) in a simulation study based on case studies of three weir sites. Subsequently he looked at the consequences of adding weirs in a watershed (Rinfret 1988). The following discussion will focus on the ways in which different aspects of the design and the planning process act to facilitate local participation.

PLANNING

* **Sizing based on existing stream channel**
* **Simple, standard design**
* **Variable crest**
* **Construction by voluntary local labor**

Facilitates:

* **Making design decisions in the field**
* **Responding to local requests**
* **Enhancing existing people's irrigation systems**

Several aspects of the design facilitate a more participatory-planning process, including sizing the structure according to the existing stream channel, use of a simple standard design, the variable crest, and construction by local voluntary labor. Most projects were initiated by requests from villagers. The planning itself was carried out through a series of meetings between project staff and village leaders (formal or informal) which allowed opportunities for developing a consensus on whether to build the weir and on other key decisions.

Sizing the structure according to the current stream channel makes the design more flexible reducing the technical considerations involved in design. The design takes up almost no land outside of the stream bed. This means that complicated negotiations to obtain land are reduced or avoided. The flexibility of the design increases the number of potential sites and the potential for being able to use the sites suggested by farmers. This makes it much more likely that the structure can be located at the sites of existing locally built earth weirs. About 80 percent of the weirs built by the project were built at sites where villagers had previously built earth weirs.

The standard design reduced the need for technical input in planning and allowed more scope for responding to local requests. There are additional guidelines such as locating on a straight stretch of stream and checking the foundation but these are not very restrictive. The main design factors which need to be taken into account are the depth and width of the current channel. Once the basic dimensions of height and width have been chosen there is little need for fine tuning of the design. This means that more effort can be directed to other activities.

The variable crest is a key part of the design which allows sizing the structure according to existing stream channels and assumes local participation in operation of the structure. One major area of disagreement between farmers and designers is the height of the fixed weir crest. Local people consistently prefer that crest heights be set at levels much higher than preferred by engineers and technicians. The best explanation seems to be that local preferences are set by the desire to be able to divert water into fields even during periods of low flow. Despite the flexibility offered by stoplogs, villagers want to reduce the effort involved in adjusting the stoplogs and monitoring the stream.

There is also a problem of majority decision making because the costs of weir failure if the structure washes out or the stream channel shifts are usually heaviest for the one or two villagers whose land lies directly next to the weir. For most potential users failure does not represent a direct threat to their land but only the opportunity cost of lost irrigation. Constructing weirs which then wash out has already been part of the continuing pattern of construction and reconstruction of earth weirs.

What seems to have happened during the Khon Kaen University-New Zealand (KKU-NZ) project is that in the end, the weirs were designed with weir crests set according to the design guidelines, at most filling 60 percent of the cross sectional area of the stream and often less than that. Villagers were told that they could observe the use of the weir and raise the crest level later if they felt that was justified by experience.

However, in the subsequent People's Volunteer Weir Program there has been more accommodation of local requests, leading in a number of cases to weirs with crests at or above the level of adjoining fields. Levees along the stream still allow for some water control but such sites are unlikely to stay in operation in the long run where floods occur with strong enough flows to dig new stream channels.

The variable crest thus is a key element of the design but one in which there is still a tension between local desires and the technical requirements of the design.

Requiring voluntary local labor encourages the planners to involve local people and be responsive to their needs, otherwise the project would be much less likely to be built. The requirement that the weirs be built using voluntary local labor plays a key role in improving site selection. It encourages local people to more carefully weigh their need for a weir. The design itself facilitates the use of this requirement by allowing for construction mainly by unskilled local labor, use of existing village technicians, and avoiding the need for extensive outside guidance in construction.

The project did not impose a particular model of how farmers were to organize. Formal water users' organizations were not established. For the most part the project left it to local people to decide how to organize themselves in planning and construction. The main recommendation the project did make was to divide workers into several groups with one group working each day so that people still had opportunities to carry out other activities. Leaving most decisions to villagers allowed a management pattern which fit much more closely with existing local institutions for resource management. These patterns were ones of episodic mobilization rather than routine activities through formal organizations.

The People's Volunteer Weir Project of the Department of Local Administration has taken up the approach developed by the KKU-NZ project and implemented it on a wide scale. However, in some cases, rather than spending the time needed to develop a strong local consensus about providing labor some officials have instead implemented the program in a top-down manner. In some cases local officials used such pressure for local people to build weirs that instead of being called people's volunteer weirs they were called conscript volunteer weirs. Thus, requirements for local contributions need to be carefully assessed in light of how they will actually be implemented in the field as routine activities in a large-scale program rather than in a special pilot study. Nevertheless, if implemented through dialogue with villagers, with enough time, and where villagers have a real choice about whether to contribute or not, a requirement for local contributions can play a valuable role in making implementation more responsive to local people.

The consequence of the design characteristics discussed above is that the major design decisions can be made in the field in active consultation with farmers. They do not require preliminary analysis of expected flows, nor complicated modifications of the basic design. Planning does not have to be done by an agency with strong technical skills. In actually selecting the site the focus can be more on the local people's requirements rather than on technical considerations. The standard design is small and flexible and easily lends itself to being built at the sites of existing people's irrigation systems.

CONSTRUCTION

*** Standard dimensions**
*** Vertical walls**

*** Use and develop local skills**

The design uses standard dimensions as much as possible for such things as the thickness of walls and the spacing of steel. This makes it easier to learn how to build the weir and reduces the need to rely on blueprints and careful planning of construction. This standardization involves sacrificing some opportunities for minimizing costs by reducing steel or concrete in less critical parts of the structure. At the same time it may also lead to lower margins of safety in some parts than could be obtained with some design modifications. However, it means that construction is easier and more likely to be done accurately than with a more complex design.

Use of a simple, standard design means that construction is within the capacities of trained local technicians. Every village has local people with experience working with concrete. Many villagers go off to work in construction in Bangkok or a provincial capital and then return to farming. A village technician who has helped to build one weir acts as a supervisor in the construction of later ones. There is still some need for supervision from a more experienced technician or engineer through visits every few days to help deal with problems or questions which cannot be answered by the village technician who stays at the site full time.

The weir is designed to be robust, "insensitive to inaccuracy in construction technique" (Mayson 1983:9). Use of vertical walls in the structure also means that compaction of earth fill is not a major problem. This avoids one potential source of failure which is a common problem even for weirs built by contractors.

Altogether, the design characteristics discussed in this section and the previous one mean that construction does not require much in the way of specialized skills. Construction does not require specialized agency staff or experienced contractors. Instead, village technicians are trained in how to build the structure and they work with unskilled local villagers to accomplish the task.

OPERATION

* **Variable crest**
* **Berm flow through adjoining fields**
* **Bridge**

* **Allow responsiveness to variable stream-flows**
* **Keep continuity with earlier patterns of water management**

Use of stoplogs in the design assumes local participation in operation and maintenance. This contrasts with the design philosophy used by the Royal Irrigation Department which builds structures that can survive even if there is little or no local operation and maintenance, with no stoplogs or only low ones. The KKU-NZ weirs instead assume that stoplogs will be used and that boards will be removed in order to pass high flows through the weir.

The adjoining fields are an essential part of the irrigation system since they are used to handle flows beyond those which can go through the stream channel. Thus, the weir is not operated in isolation but is rather just an added component in the existing farmer-modified hydrological system. Like earth weirs, the KKU-NZ weirs divert water into fields adjoining the weir and even slightly upstream. Thus, they maintain the current irrigation pattern, rather than being built with the more conventional design assumption that canals are used to deliver water to lower lying fields located away from the weir.

Use of stoplogs may mean that a concrete weir requires more effort to operate than an earth weir. Earth weirs usually have only pipes through the weir or a narrow spillway in which boards can be placed. In either case, the main tactics for coping with floods are either to let them flow through the fields and hope there is not too much damage or else to intentionally breach the weir. Construction of a concrete weir with stoplogs means that it is possible to let much more water flow through the weir than can be done with an earth weir.

Stoplogs are also one of the key points of conflict over weirs. Fish are a major source of protein in the diet of northeastern villagers. The area just downstream of a weir is usually a good location for fishing. Removing boards from the weir can increase the chances of catching fish, and so fishermen often remove boards without permission, in both wet and dry seasons. This creates a major problem for farmers who want to manage a weir for irrigation. In areas where water becomes very scarce in the dry season villagers successfully forbid opening the stoplogs. In other areas where water is not as scarce, farmers may give up trying to prevent fishermen from opening the weir, with the consequence that the potential for water storage in the dry season is not fully used. In some cases farmers resort to nailing the boards in place. While this may not cause problems in the dry season, it does hamper operation of the weir in the wet season.

As best as could be determined, problems in weir operation were not the source of failure for the five weirs which were no longer usable at the time of the evaluation. Farmers often remove boards from the weir much later than would be optimal, i.e., they wait until the water is threatening to overtop the levees along the stream channel into adjoining fields rather than removing the boards as soon as water starts to rise after a storm. In part, this is because of the uncertainty about how high water will rise and the desire to move as much water as possible into the fields as quickly as possible. Since irrigation relies on stormflows which often only last for a period of a few days or less there is a high premium on making the most of water while it is available. Usually the farmer or farmers with fields next to the weir, who are most threatened by flood damage, take the initiative in removing the boards.

In some cases the stream rises too quickly and flows become too strong for farmers to remove the boards at all, in which case the weir may operate more like an earth weir, with little of the stormflow carried through the stream channel. Despite this, the weirs seem to have survived well, perhaps because floods rise relatively slowly, because farmers are experienced in coping with floods going through their fields, and because the concrete structures do not wash out as easily as earth weirs when they are overtopped.

One of the results of the assessment of the weirs done in 1985-1986 was the recommendation that a bridge should be a standard part of the weir design. Without a bridge, removing boards can be difficult and dangerous during periods of high flow. Including a bridge thus facilitates local operation and increases the chances that the stoplogs will be used to manage flows.

MAINTENANCE

* **Elephant ears**
* **Crocodile teeth -- riprap not relied on**
* **Vertical walls**

* **Reduce susceptibility to damage**
* **Reduce need for preventive maintenance**

Several aspects of the design prevent or reduce maintenance problems. This fits with the approach farmers generally take towards maintenance which emphasizes making urgent repairs when necessary. A major benefit compared to earth weirs is that it is no longer necessary to mobilize resources to rebuild earth weirs each year. When earth weirs fail after fields have been planted it is often impossible to repair or rebuild them since earth is no longer available.

Routine maintenance of private fields is done by individual households at the beginning of the growing season. Some repairs of collective goods such as weirs may go on but is much harder to organize and occurs fairly infrequently. As with construction, the pattern for maintenance relies on episodic mobilization rather than on routine activities.

The design does not have portions which require routine maintenance, e.g., oiling of gates. Wingwalls help to prevent water from washing or seeping around the structure. These walls flanking the weir on each side are often referred to as elephant ears. Many earlier weirs were built without such walls and have quickly failed. In addition to the walls on each side, there are cutoff walls reaching below the structure which again help to prevent seepage of water past the structure which could in time lead to failure.

Crocodile teeth is the name farmers give to the energy dissipation blocks which are placed on the downstream apron of the weir. These are intended to reduce the downstream erosion which is a common problem of small weirs. The evaluation suggested that these were at best partially successful and that further solutions should be sought. However, the cutoff wall at the downstream side of the weir does provide a substantial margin of safety against erosion actually damaging the weir.

The blocks are at least a better approach than the common use of rock riprap, placed on the areas downstream of the concrete portions of the structure. While riprap may in theory be effective at reducing erosion, it is ineffective in practice. The rocks tangle nets and make fishing difficult and so fishermen remove them. While those who irrigate from a weir usually only come from a few nearby villages, people who fish at a weir often come from a dozen or more villages. This means that it is very difficult to enforce regulations such as prohibiting removing riprap, unless the weir is located very close to a village. Thus, blocks and a deep cutoff wall at the downstream end of the structure are more suitable methods for preventing erosion.

In the case of maintenance, it can be said that the weir is designed to cope with the relative lack of maintenance, especially routine preventive maintenance which is accomplished by local management. Participation in construction does help give local people an understanding of how the weir was built and the skills needed to carry out repairs.

CONCLUSIONS

It is possible to design for participation. This paper has used the example of the Khon Kaen University-New Zealand (KKU-NZ) project weirs to illustrate some specific elements of a design which facilitates local participation in planning, construction, and operation of small weirs. Key aspects of the design include sizing the structure according to the existing stream; use of stoplogs to make a variable crest; a simple, standard, robust design; vertical walls; stilling blocks; and a bridge.

These design elements facilitate participation in a number of ways. They make it possible to make the major design decisions in the field in consultation with farmers. The design is flexible enough to be used at many locations, so it is easier to respond to local requests and to enhance existing earth weirs. The weir can be built by local technicians and unskilled villagers. This makes it possible to require construction by voluntary local labor which in turn provides a strong incentive for those involved in planning to work with villagers in a participatory way. The use of stoplogs assumes local operation and makes it possible to manage the weir in ways very similar to existing people's irrigation systems. Several aspects of the design prevent maintenance problems and avoid the need for routine maintenance which is difficult for villagers to organize.

The specific elements of the design are adapted to the particular conditions of northeast Thailand and may not be very transferable to other areas. The needs and opportunities in irrigation development in other areas differ. In northeast Thailand diversion of stormflows is the principal irrigation task, rather than acquiring water, conveying water to fields, allocating water, drainage, or other tasks.

Problems concerning the weir now are what might be called problems of success. Programs to build People's Volunteer Weirs have led to construction of the weir in mountainous areas where the hydrology is quite different and where the availability of rocks and better foundation conditions mean that construction can be done even more cheaply using mortar and local stone. Also, specific programs have urged building only weirs of this type rather than making them a part of a menu of options for developing water resources, to be chosen by local people according to their needs and conditions. What may be more relevant for other areas of Thailand and for other countries are not the specifics of the weir design but some of the processes and principles which underlie specific design elements.

The most important factor encouraging development of a more participatory design was the learning process of working with villagers, which went into creating and improving the design. Past attempts at irrigation development have yielded a rich diversity of natural experiments. Unfortunately, the lessons of this experience are too often neglected. A small, flexible, university-based project provided a good environment for innovation. The process of studying earlier projects and then of following up on new construction within the context of a flexible, applied research project has considerable potential as an approach for creating appropriate innovations.

The intervention in the project was highly focused on the key irrigation problem faced by farmers. Energies were not dissipated on creating formal water users organizations, constructing distribution systems, or training farmers in irrigated agriculture. The assumption was that farmers could manage these activities on their own. Construction took advantage of existing irrigation structures and existing institutions for mobilizing resources.

The design that was developed was adapted to the particular conditions of northeast Thailand. In developing such an innovation, engineering knowledge had to be combined with the knowledge of local farmers. The willingness to experiment and take risks and the goal of a truly low-cost design were major factors encouraging innovation. The development of variable crest weirs in northeast Thailand shows the potential benefits which can come from a process directed at learning how to enhance existing locally managed irrigation systems in a participatory way.

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