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Wastewater Irrigation of Rice

Technical Report

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by

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Land Treatment Task Force

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Ada, Oklahoma

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U.S. Environmental Protection Agency

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Municipal Construction Division

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Disclaimer Statement

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Comment

This bulletin was prepared as one of a series of reports to finish information on studies and current practices on use of municipal effluents for crop production. It was prepared in response to many requests for technical guidance on this topic.

The overall series provides indepth presentations of available information on topics of major interest and concern related to municipal wastewater treatment and sludge management. It is a continuing effort to provide current state-of-the-art information concerning sewage and sludge processing and disposal/utilization alternatives, costs, transport, environmental influences, and health factors.

These reports are not a statement of Agency policy or regulatory requirements. They are published to provide planners, designers, municipal engineers, environmentalists and others with detailed information on specific municipal wastewater treatment and sludge management options.

Harold P. Cahill, Jr., Director
Municipal Construction Division
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WASTEWATER IRRIGATION OF RICE

by

Jack L. Witherow*

Summary

The three areas evaluated in this report are: the potential for and extent of wastewater reuse in rice production, the resulting food chain effects, and the cost effectiveness of this reuse.

Rice irrigation occurs in Arkansas, Louisiana, Texas, Missouri, Mississippi and California and uses 2.8 million acres of land and over 8 million acre feet/year of water. In the counties with large acreage in rice production, there are over 400 small or medium size communities having a combined wastewater discharge of about 100,000 acre feet/year. There are also three metropolitan areas with an estimated combined discharge of 400,000 acre feet/year. The water requirement for rice irrigation far exceeds the local wastewater discharges. Many small or medium size municipalities have a high potential for a land treatment system, which could reuse wastewater in rice irrigation.

Six cases of municipal wastewater reuse for rice irrigation were found in the Central Valley of California. These treated municipal wastewaters constitute up to 75 percent of the waters used to irrigate rice. Treatment presently consists of primary units and oxidation ponds. However, these cases of wastewater irrigation of rice have been ongoing for 30 or more years, and some municipalities had only primary treatment until recently.

The published literature documented wastewater irrigation of rice outside of the U.S. and showed a worldwide practice of wastewater rice irrigation with one or more cases in the countries of Italy, Taiwan, Japan, China, India and USSR. A case where industrial wastewaters were used in Japan and another in Taiwan indicate the benefits of organic matter and the detriment of soluble solids to rice yields, respectively. A case in USSR, using municipal wastewater which is mostly domestic, had preapplication treatment similar to that recommended in EPA's Construction Grants Program Requirements Memorandum (PRM) 79-3. The treated wastewater applied to the rice paddies had an average BOD_5 of 39 mg/l.

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After two days' retention in the paddies, the discharge had a BOD_5 ranging from 1.5 to 2.0 mg/l and total bacterial counts ranging from 10 to 300/ml.

The potential for introducing a health hazard into man's food chain is through metal contaminants, biological contaminants, and biocidal contaminants (toxic chemicals). Of the three, metal contaminants have resulted in the only known health hazard in wastewater irrigation of rice. This was a case of untreated industrial wastewater, adding cadmium to the water used in nearby irrigation of rice.

Many metal contaminants are not significant potential health hazards because they are generally present in low concentrations, are not readily taken up by plants, or are not very toxic to man. Several heavy metals (particularly Cd, Zn, Mo, Ni, Cu) are labelled as posing a potential health hazard. A compilation of greenhouse and field experiments has indicated particular circumstance and levels of heavy metals which should be avoided. For example, to prevent health problems, zinc and cadmium should be maintained in the soil at less than 500 mg/kg and 40 mg/kg, respectively. The "Process Design Manual for Land Treatment of Municipal Wastewaters," (EPA 625/1-77-008), Table 5-4 lists maximum application of these and other metals "without need for further investigation." The inclusion of industrial wastewaters into the municipal system is the cause of metal exceeding these maximum values. Thus a review of the industrial sources, analyses of suspected metals from these sources, and use of Table 5-4 will prevent this potential health hazard.

Biological contaminants in food have been extensively studied. Bryan has compiled a lengthy list of disease outbreaks through foods which were irrigated with wastewater. Examination of the list shows that the outbreaks occurred with food eaten raw. Rice, like wheat, is a cereal crop which is not eaten raw. However, unlike wheat, a part of the rice harvested is eaten in the grain form. This causes special concern because of the direct prolonged contact of the rice with the irrigation wastewater. There are a number of factors which reduce this potential hazard to the food chain to nonsignificant levels. Pretreatment and the six to nine month storage of the wastewater greatly reduce the parasites, bacteria and virus. The hot air drier used to reduce moisture prior to storage of the grain further reduces any surviving pathogens. Milling removes the surface of the grain which contacted the wastewater. Most significant, however, is the necessity of cooking at a boiling temperature prior to human consumption.

Biocidal contaminant investigations have been made on the common toxic organic chemicals used in rice production. The concentrations required to increase the uptake or residual on the unhulled rice grain are two to four orders of magnitude greater than the concentration of these types of compounds in domestic wastewater. The placement of toxic persistent organics in man's food chain will not occur via irrigation of rice with domestic wastewater. However, an industrial discharge with high levels of biocidal contaminants would need to be evaluated prior to reuse in the irrigation of rice.

A cost comparison of three land treatment schemes was made to determine if wastewater irrigation of rice is cost effective. The land and capital costs for nine months of wastewater storage for rice irrigation was compared with two months of storage plus forage irrigation and with one month of storage plus an overland flow process. The overland flow system is expected to have less land and capital costs than nine months of storage. The forage irrigation system will have capital costs similar to nine months of storage. The costs of land treatment systems are very site specific, but these comparisons show that an overland flow or a forage irrigation system may be cost effective and should be fully evaluated. Controlling factors which must be added to these cost comparisons are: site characteristics, differences in transportation distances, crop revenues, operation and maintenance, and purchase of the water or storage by the rice farmer.

Recommendations

Wastewater irrigation of rice should be viewed as having the same health hazards as wastewater irrigation of wheat or other controlled agricultural food crops which are not eaten raw. (PRM 79-3 recommends prior to reuse: "Biological treatment by lagoons or inplant processes plus control of fecal coliform counts to less than 1,000 MPN/100 ml.")

The industrial discharges to the municipal systems should be inventoried and analyses made of heavy metals and persistent organics that are suspected of being present and of being a health hazard to man. If concentrations of these materials are less than those maximum values in the "Process Design Manual for Land Treatment of Municipal Wastewater" or less than the toleranceresiduals levels of the commonly-used registered biocides, the treated wastewater should be acceptable for reuse in rice irrigation. If the concentrations are greater, several courses of action should be considered. Among these are denying approval for reuse on rice irrigation, requiring pretreatment to reduce the concentrations to acceptable values, or approving reuse on the condition that annual monitoring of the soil and crop for heavy metal and persistent toxic organic show concentrations below recommended values.

Monitoring and reporting requirements should be established to determine new industrial discharges to the municipal system that contain heavy metals or persistent toxic organics, and to determine the environmental quality of water discharged from the storage lagoons and the rice paddies to both surface and ground water sources.

Potential for and Extent of Reuse

The potential for reuse of municipal wastewater for irrigation of rice is dependent upon the acreage of rice grown and the amount of local wastewater. Annual rice production of 12 billion pounds in the United

States is derived from about 2.8 million acres. The producing states are Louisiana, Arkansas, Texas, California, Mississippi and Missouri. The breakdown of the 1975 production by acres, pounds, and dollar value is shown in Table 1.

TABLE 1. 1975 RICE PRODUCTION (1)

States	Acres	Cwt.	Dollars
AR	882	40,053	322,427
CA	525	30,088	225,660
LA	658	25,064	177,954
MS	171	6,665	54,320
MO	18	758	6,102
TX	548	24,996	224,964
TOTALS	2,818	126,624	1,011,427

(1) in thousands

To establish feasibility, the extent of existing wastewater irrigation of rice was determined. However, the United States has only 1 percent of the acreage used for rice cultivation throughout the world, and the practice of irrigating rice with wastewater was found to be more common in foreign countries.

Arkansas - Rice is produced in 35 counties in Arkansas, mostly in the eastern half of the state. Counties having the largest acreage ranked in order are: Arkansas, Prairie, Lonoke, Poinsett, and Cross. In counties with substantial rice production, there are several cities and numerous small towns. Each county has about a dozen small towns with less than 1,000 population, and two communities with populations between 1,000 and 5,000. The cities of Pine Bluff, Stuttgard, Searcy, Jonesboro, and Forest City are located in heavy rice-producing counties. These cities with populations over 10,000 have sufficient wastewater to irrigate several hundred acres of rice. A consultant for Searcy has made a preliminary investigation and proposed a scheme to use that city's wastewater to irrigate part of 10,000 acres of nearby rice production.

An ample supply of irrigation water is necessary for successful rice production. About 33 inches of water are required to produce a rice crop in eastern Arkansas. Twenty to 24 inches of this amount will have to be supplied by irrigation. The amount of irrigation water needed will vary depending upon the amount and distribution of rainfall, humidity, temperature, evaporation, type of soil, and water management. This last item, water management, can overshadow the others. USDA personnel in several states have stated common practice is to apply between seven and ten feet of water, consume about three feet, and discharge the rest.

Texas - The principal Texas rice-growing area is in 19 counties making up the physiographic area of the gulf coast prairie. The rice production in Texas is presently between five and six hundred thousand acre. The Texas Water Development Board has predicted that by 2020, the acreage in rice will have doubled in Texas. The gulf coast rice belt is highly industrialized and populated. The area includes Houston, the largest city in the state, and over 50 other smaller communities. Water usage in rice production exceeds the municipal wastewater discharged in this area.

Louisiana - There are two principal rice-growing areas in Louisiana. These consist of seven parishes (counties) in the southwest and six parishes in northeast parts of the state. The southwest parishes with the largest acreage in rice production are Jefferson Davis, Acadia and Vermilion. There are about 10 small communities in each of these three parishes. The only large municipalities, Lake Charles and Lafayette, are in adjacent parishes, and transport distance will likely prevent wastewater irrigation of rice. In the northeast area, Morehouse and Richland are the parishes with the largest acreage in rice production. In each parish, there are less than 10 small communities. Monroe, the only city in northeast Louisiana, is in Quachita parish, and rice is grown in this parish. The opportunity for irrigation of rice with municipal wastewater in Louisiana will be mainly small communities and Monroe. Between 30 and 36 inches of water are consumed to produce rice in Louisiana. Thus, each acre of rice irrigated will require a sewered population of 35 to 40 people.

Mississippi - The rice growing area is in the west central portion of the state. Most of the rice acreage is in Bolivar, Washington, Sunflower, LeFlore, Tunica, Coahoma, Humphrey and Sharkey counties. This acreage is concentrated in the flood plains of the Mississippi, Sunflower and Tallahatchie rivers. These counties contain 80 small communities and the larger municipalities of Greenville, Greenwood and Clarksdale.

Missouri - Of the six rice-producing states, Missouri has the smallest acreage in rice cultivation. Rice is grown in the southeast part of Missouri. The principal rice-growing counties are Butler, Ripley, and Stoddard. In these counties, Popular Bluff, with a population of about 17,000, is the only large community, but there are also 40 small communities. The opportunities for irrigation of rice with municipal wastewater will be limited to a few communities with nearby rice paddies.

California - California has wastewater reclamation criteria for irrigation of food crops. The required levels of preapplication treatment would in almost all cases produce an effluent suitable for discharge. However, exceptions are made to the required quality of the reclaimed water when it is to be used to irrigate a food crop which must undergo extensive commercial, physical or chemical processing sufficient to destroy pathogenic agents before it is suitable for human consumption.

Wastewater irrigation of rice is being practiced in a limited manner in California.

In California, water consumption is about 36 inches per year for rice production. Application of the seven to nine feet per year is practiced with most going to the drainage system. Irrigated agriculture in the Central Valley is highly organized through irrigation districts and water rights. The rice-growing areas are located in 16 counties. Most of the acreage is in Butte, Colusa, Fresno, Glen, Sacramento, Sutler, Yolo and Yuba. All of these counties except Fresno are located in the northern half of the Central Valley. There are between 13 and 25 small communities in each of these northern counties. In the rice-growing areas, there are three communities with populations between 40,000 and 60,000, but Fresno and Sacramento are the only major cities.

Extent of Reuse in the U.S. - Water reuse is common and highly encouraged by the state of California. Irrigation water transport and drainage canals are publicly owned. Wastewater from several segments of society are discharged to these public-funded canals. The State is not aware of rice paddies wholly irrigated by municipal wastewater; however, there are a number of small towns in the northern part of the Central Valley that for 30 years or more have been discharging their wastewater into a drainage system. All of these small towns now have primary treatment followed by oxidation ponds. This wastewater is used for the irrigation of rice.

Examples of irrigation of rice with wastewater provided by California's Central Valley Water Quality Board follow:

(1) The town of Colusa discharges about 0.5 mgd into Powell Slough. The flow in the slough is half treated sewage and half irrigation return flow. A farmer has been using this water for irrigation of rice for a number of years. Until just recently, the sewage received only primary treatment. The farmer recently initiated a suit against the City to retain use of their wastewater for rice irrigation.

(2) The town of Willows also discharges 0.5 mgd into a public drain which constitutes half of the flow in the drain. This is used for irrigation of rice.

(3) The town of Williams dicharges about 0.5 mgd into Salt Creek which represents up to 75 percent of its flow. This water is used to irrigate rice and other crops.

(4) The small town of Biggs discharges their wastewater to a drain. The discharge is about 10 percent of the flow and the water is diverted to irrigate rice and other crops.

(5) Some of the wastewater from the town of Live Oak is used in a similar manner for rice irrigation.

(6) The town of Maxwell discharges its wastewater into Stone Corral Creek, which flows into the Glenn-Calusa irrigation district's irrigation canal. The municipal wastewater, which is about 10 percent of the flow, is used to irrigate rice. This irrigation district included 121,170 acres of cropland in 1978, 3/4 of which were devoted to rice production.

Both the Regional Water Quality Board and State Health Department are aware of the uses of treated municipal wastewater for rice irrigation and do not feel a change is necessary, as problems have not occurred from these long standing practices.

In Arkansas, Texas, and Louisiana, rice is a major cash crop, and they all have experimental stations which specialize in research on rice production. These experimental stations are located at Stuttgart, Arkansas; Beaumont, Texas; and Crawley, Louisiana. All three stations are part of the agricultural research program directed from the states' land grant colleges. Contact was made with these stations, but information was not available on wastewater irrigation of rice in these states.

Foreign - A literature search was made in June, 1979 by EPA's library services. This computer-based search of articles on rice irrigation with wastewater, sewage, or sludge located eight articles.

This limited list shows rice irrigation with wastewater has been practiced in Italy, Taiwan, Japan, India, and USSR since 1969. The small number of references is probably due to the fact that computer-based bibliographies were begun in the last decade and seldom contain literature published prior to 1960. Outside of establishing that rice irrigation with wastewater is practiced around the world, several of these articles are germane to conditions that can be expected in rice-growing areas in this country. Two of the articles relate the increase or decrease in rice yields to various constituents in industrial wastewater.

Minami showed that yields increased with increasing BOD of the water up to 50 ppm (COD 200 ppm), but above this level yields decrease. High-level BOD water produced reducing conditions in the soil and promoted the leaching of inorganic elements (Fe, Ca, Mg) with an associated increase in acidity. The wastewater was pulp mill sulphite liquor that had been neutralized by dilution with river water. Huang found rice yield loss as high as 89 percent when wastewaters from a paper mill or an acetyl chloride plant were used as a part of the irrigation water. The results of analysis indicate that both industrial wastewaters and the polluted irrigation waters were not acceptable for irrigation purposes because of high soluble solids and salts.

The most significant article is by Koltypin, who describes the pre-application treatment and use of sewage in rice paddies in the USSR. The wastewater was from Dushanbe and consisted of 60-65 percent domestic sewage and 35-40 percent industrial effluent. The wastewater was treated in four ponds in series, used in eight to twelve rice paddies in series, and discharged. The first pond served as a settling tank with an area of 2 ha (4.4 acres), a depth of 1.5 m (5 ft) and a detention of 10 hours. The subsequent biological ponds had areas of 4 to 4.5 ha (10 to 11 acres) and a depth of 0.6 m (2 ft). The quantity of wastewater discharged was 58,200 m^3/day (15MGD). The detention time in the three biological ponds was 33 hours, and the BOD_5 loading was 672 kg/ha/day (600 lb/acre/day). The rice paddies had a total area of 25 ha (62 acres) with a mean water depth of 25 cm (10 inches). Their total water capacity was 62,500 m^3; the inflow was 52,200 m^3/day and the discharge was 30,000 m^3/day. Thus the detention was about two days.

A part of the analytical results are reported in Table 2.

TABLE 2. REMOVALS IN LAGOONS AND RICE PADDIES

Items	Raw Waste Ave*	Pond Effluent Ave*	Paddy Effluent Min	Paddy Effluent Max
BOD_5 (mg/l)	120	39	1.5	2.0
Dissolved oxygen (mg/l)	0	3	8.5	12.0
Helminth eggs (per liter)	23	0	0	0
Ammonia (mg/l)	--	--	0.5	1.0
Total bacterial (counts/ml)	--	--	10	300

*Mean value from 26 determinations.

The aquatic organisms in the paddies included algae, diatoms, dragonfly larvae, carp, and mosquito fish. The system depends upon both the ponds and rice paddies for treatment. The effluent from the paddies is highly treated.

Koltypin concluded "Extensive utilization of paddy fields for the decontamination of sewage is possible in the rice-cultivating regions of the USSR. In the vicinity of cities, with industrial-type sewage treatment installations already in operation or under construction, paddy fields may be used for the additional purification of sewage after leaving the aeration tanks and biofilters. In many cases, with small volumes of effluents from enterprises, rest homes, pioneer camps, and other similar sources, paddy fields may be combined with biological ponds. Finally, paddy fields may become an essential component of sewage farms in the zone of rice cultivation in the south of the USSR."

These treatment ponds are more heavily loaded and have shorter detention than those used in the U.S. In the U.S. where the wastewater is to be used in controlled agriculture fields and on human food crops not eaten raw (ie. rice), PRM 79-3 recommends preapplication treatment by either biological lagoons or inplant processes plus control of fecal coliforms to less than 1000 MPN/100 ml.

Metal Contaminants - The food chain involves acquisition of the metal by rice plant roots, transport into the rice grain, and then consumption by man. Many metals are not a significant potential hazard either because they are generally present in low concentrations, are not readily taken up by plants under normal conditions, or are not very toxic to plants and/or animals. Several metals (particularly Cd, Zn, Mo, Ni, Cu) are labeled as posing a potential serious hazard under certain circumstances.

Except for certain accumulation species, plants are excellent biological barriers. This is notably true for nickel, copper, and lead. Molybdenum is an exception to the plant barrier rule, but only ruminants that consume forages can be affected. Zinc can be transferred to foliar tissue such as spinach and to the edible tissues of other plants such as tomato, peas, and potato. Soil levels of zinc in excess of 500 mg/kg may cause, at least, a decline in forage quality through lower palatability and at worst some overt toxicity symptoms. Humans are probably protected from food-chain transfer toxicity because their diet also includes fruits, grains, and animal meats. In all cases, zinc transferred from substrates high in zinc is much lower in these tissues than in foliar tissues of plants.

Cadmium is currently the element of greatest concern as a food chain hazard to humans. The widely publicized Itai-Itai disease in Japan is attributed to cadmium introduced into the Jintsu River from mining activities which was transferred to man through several sources, including irrigated rice. The World Health Organization has recommended a safe value of 400 to 500 µg/week of cadmium. The base level average dietary intake of cadmium has been reported to range from 175 to 525 µg/week for an adult consuming 1.5 kg/day of food. Cadmium intake of the people affected by Itai-Itai disease may have been 4200 to 7000 µg/week. The limit recommended by the Japanese investigations as the maximum permissible concentration was 1.0 µg Cd/g of rice grain. Their results associated a concentration of 15.5 µg Cd/g extracted from the soil with 0.1 N HCl with excessive levels of Cd in rice grain.

Two important foodstuffs, rice and wheat, are able to take up considerable quantities of Cadmium from soils. Kobayashi et al. added cadmium oxide to soil in pots where rice and wheat were growing. The results are in Table 3. The wheat grain accumulated more cadmium than did rice. Concentrations above 10 µg/g (.001 percent) in soil reduced the yield of both rice and wheat. However, concentration of 100 µg/g in the soil did not result in the rice grain's reaching the maximum level of 1.0 µg Cd/g recommended by the Japanese.

TABLE 3. UPTAKE OF CADMIUM BY RICE PLANT AND WHEAT AS WELL AS YIELD

Addition of Cd to Soil (% of CdO)	Rice			Wheat	
	Yield (%)	Polished Cd (μg/g)	Bran Cd (μg/g)	Yield (%)	Whole grain Cd (μg/g)
0	100	0.16	0.59	100	0.44
0.001	100	0.28	0.79	106	8.27
0.003	92	0.40	0.84	72	15.5
0.01	92	0.78	1.60	16	29.9
0.03	93	1.37	2.68	13	41.4
0.1	69	1.62	2.94	3	60.7
0.3	32	1.94	3.19	3	48.6
0.6	19	1.73	3.94	2	90.8
1.0	1	4.98*		1	139.0

*Unpolished
From Kobayashi et al., 1970.

Bingham et al., in a greenhouse investigation conducted in California in 1975, showed the uptake of cadmium by rice grain increased with increased amount in the soil, but was much less under flooded than non-flooded cultures. Under flood and non-flood conditions, rice grain with concentrations in excess of 1.0 μg Cd/g was produced when DTPA-TEA soil extractable Cd was 40 and 15 μg/g, respectively. Thus, with flood culture rice, design calculations should be required showing an accumulation of cadmium in the soil of less than 40 μg/g. Naturally-occurring levels of Cd in soil average 0.06 μg/g and range from 0.01 to 5. μg/g (extracted with 0.1N HCl).

Biological Contaminants - Enteric pathogens survive some stages and sometimes the entire process of wastewater treatment. Viable pathogens are therefore applied to the land and the crop in the process of irrigation with wastewater. After application, the pathogens must survive long enough to be present when the crops are harvested.

The greatest health concern is with low-growing crops such as vegetables which have a greater chance of contamination and are often eaten raw. Outbreaks of disease have occurred from foods contaminated by wastewater. Bryan has compiled a lengthy list which shows outbreaks occurred with food eaten raw.

Prior to and during reuse of wastewater for rice irrigation, biological pathogens will die due to long exposure to unfavorable environmental conditions in the preapplication treatment facilities, storage ponds and rice paddies. The most common treatment facilities will be lagoons with about a month detention. Storage ponds will have 7 to 9 months detention, and the paddies will remain flooded for 3 to 5 months. Reduced water levels in the storage ponds and discharges from the paddies during the growing season will reduce these detention times.

The removal of both virus and bacteria in ponds have been shown to be time and temperature dependent. Sagik, et al., have shown the reduction of virus is quite rapid at 20°C as is illustrated in Figure 1., which is results from research in Texas. Similar results for fecal coliforms have been found in wastewater ponds, and Bowles has developed the following equation describing the die-away function.

$$t = \ln Ci/Cf \div K\ \theta^{(T-20)}$$

where: t = Actual detention time in days
Ci = Entering counts/100 ml
Cf = Final counts/100 ml
K = 0.5 in warm months
= 0.03 in cold months
θ = 1.072
T = liquid temperature (°C)

Short circuiting occurs in almost every pond. The actual detention time was found to range from 25 to 89% of the design time with a geometric mean of 46%. Using Bowles' equation, about 18 days is required to reach the recommended fecal coliform count of 1000/100 ml at 20°C. This is similar to the time required for virus removal shown in Figure 1.

Studies have been made on the viability of various pathogenic organism on crops irrigated with wastewater. The values in Table 4 show the viability of such organisms varies from less than a day to 49 days.

TABLE 4. SURVIVAL OF SELECTED PATHOGENS ON VEGETATION

Organism	Media	Survival Times (days)
Salmonella	vegetables	3-49
Salmonella	grass or clover	12->42 (and over winter)
Tubercle bacilli	grass	10-49
Entamoeba histolytica cysts	vegetables	<1-3
Enteroviruses	vegetables	8
Ascaris Ova	vegetables	27-35

Loehr, et al., 1979.

The harvested rice grain is dried, stored and milled before marketing to consumers. The drying is usually done in a multi-pass heated air drier at temperatures ranging from 110° to 130°F. Milling is a process which removes the hulls, and the bran. These are the exterior parts of the grain which comes in contact with the wastewater. All three processes, drying, storage, and milling, will reduce or eliminate biological pathogens.

Though about two-thirds of the annual rice production is exported, rice is one of the few carbohydrate-type foods found more frequently on the menu today than 20 years ago. Consumption per capita in the U.S.

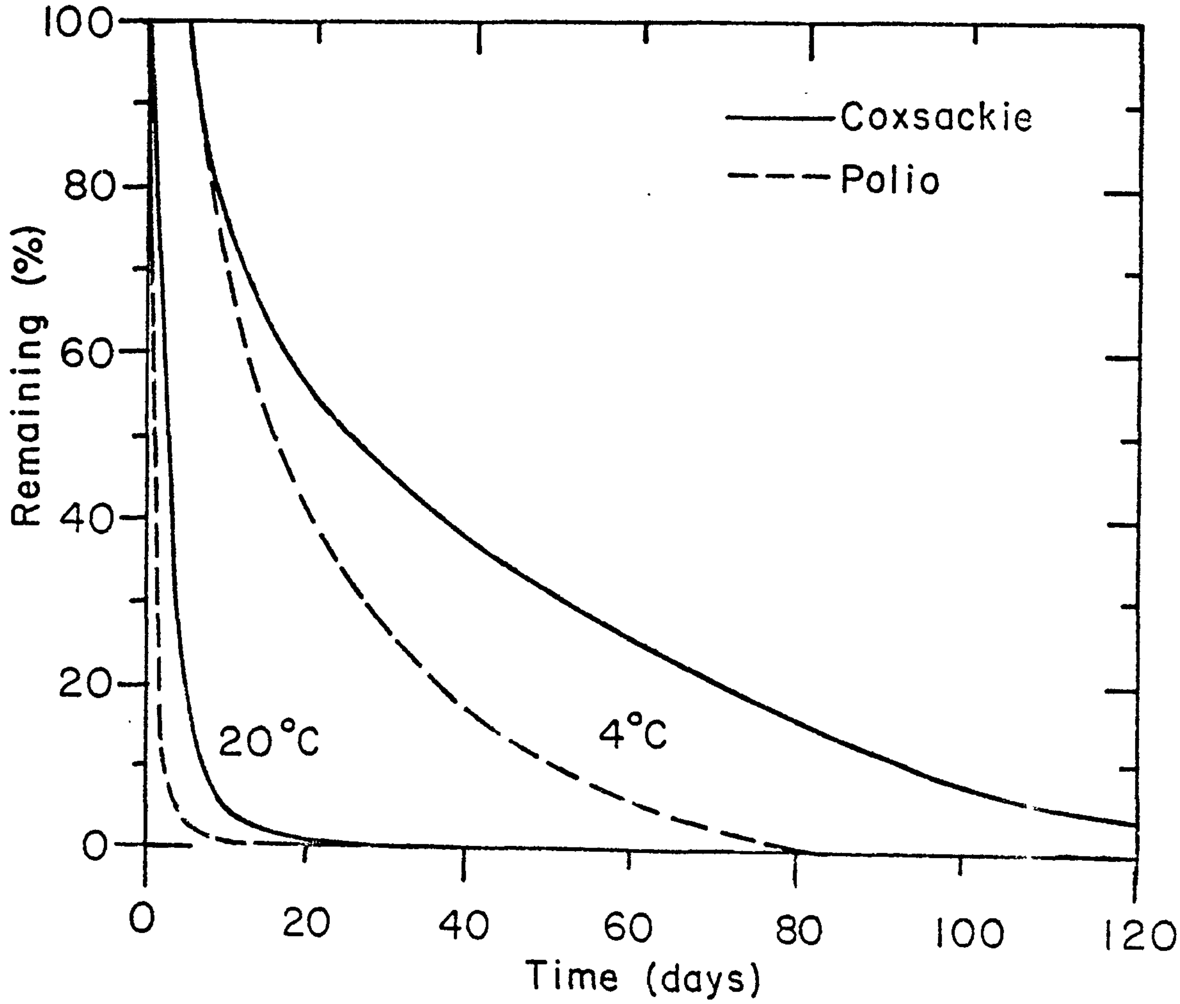

Figure 1. Virus Survival in Ponds

increased 65 percent between 1950 and 1970. Much of this increase in consumption is in breakfast cereals or specialty prepared food. These uses require high temperature processing, which will destroy biological pathogens. Direct use of rice grain requires cooking which is universally done with water at boiling temperature. The sequential and additive effects of die off in storage, heat drying, and finally cooking of the product provide a very effective barrier for biological contaminants.

Biocidal Contaminants - Biocidal contaminants can be generally described as chlorinated hydrocarbons, arsenated hydrocarbons, organo-nitrogen pesticides, organophosphorus pesticides, herbicides and soil sterilants. Some of the most recognized compounds are DDT, Dieldrin, 2,4-D, Parathion and PCB. The concentration of all of these in wastewater is negligible compared to other sources and are far below levels that will cause acute health effects.

The major concern in placing these compounds in man's food chain has been in waste discharges to drinking water sources and surface contact on foods. Because of their persistence the possibility of increased uptake by rice with increased concentrations in the irrigation water has been studied. An unpublished paper by Yin-hsiao indicates the degree of uptake in rice of a heavy metal, arsenic, and a persistent organic compound, phenol. (The major biocides used in rice culture in the U.S. are phenolic compounds, ie. Propanil, Carbofuron and Carbaryl.) In experimental plots, each with an area of 0.66 m^2 and 80 cm deep, rice was irrigated with wastewater containing 0, 0.5, 50, 100, 250, and 500 ppm of phenol and in separate plots rice was irrigated with wastewater containing 0, 5, 10, 20, and 50 ppm of Arsenic. The uptake by the rice is shown in Figures 2 and 3. These figures show the uptake in the root and in the stem and leaf is much greater than in the unhulled rice. Concentration of phenol and arsenic in the unhulled rice is the same with concentrations of 0 and 50 ppm of phenol and 0 and 10 ppm of arsenic in the irrigation water. Yin-hsiao concludes "The effect of the phenolic compounds on the crops and their accumulation in the plant is influenced by various factors (temperature, humus, etc.), especially the concentration of phenolic in the irrigated sewage. Under the field conditions, wheat, rice, and corn irrigated with a low concentration (under 1 ppm) of sewage containing phenolic compounds show a good growth and development. Their phenolic content doesn't show a distinct difference in comparison with those irrigated with clean water. But under the experimental conditions, if the phenolic concentration increases, the level of the phenolic content and its accumulation are somewhat different. When the concentration is 50 ppm, both in soil and water culture, the phenol promotes the growth. When the concentration increases further, however, the result turns to the opposite. When concentrations are over 50 ppm in soil culture, the phenolic content in the crops may be increased; as the concentration raises up to 500 ppm, the crops growth is inhibited....

"The effect of arsenic on the crops and its accumulation is obviously influenced by the arsenic concentration of the irrigated sewage.... At low concentration (1 ppm) arsenic promotes the growth of wheat and

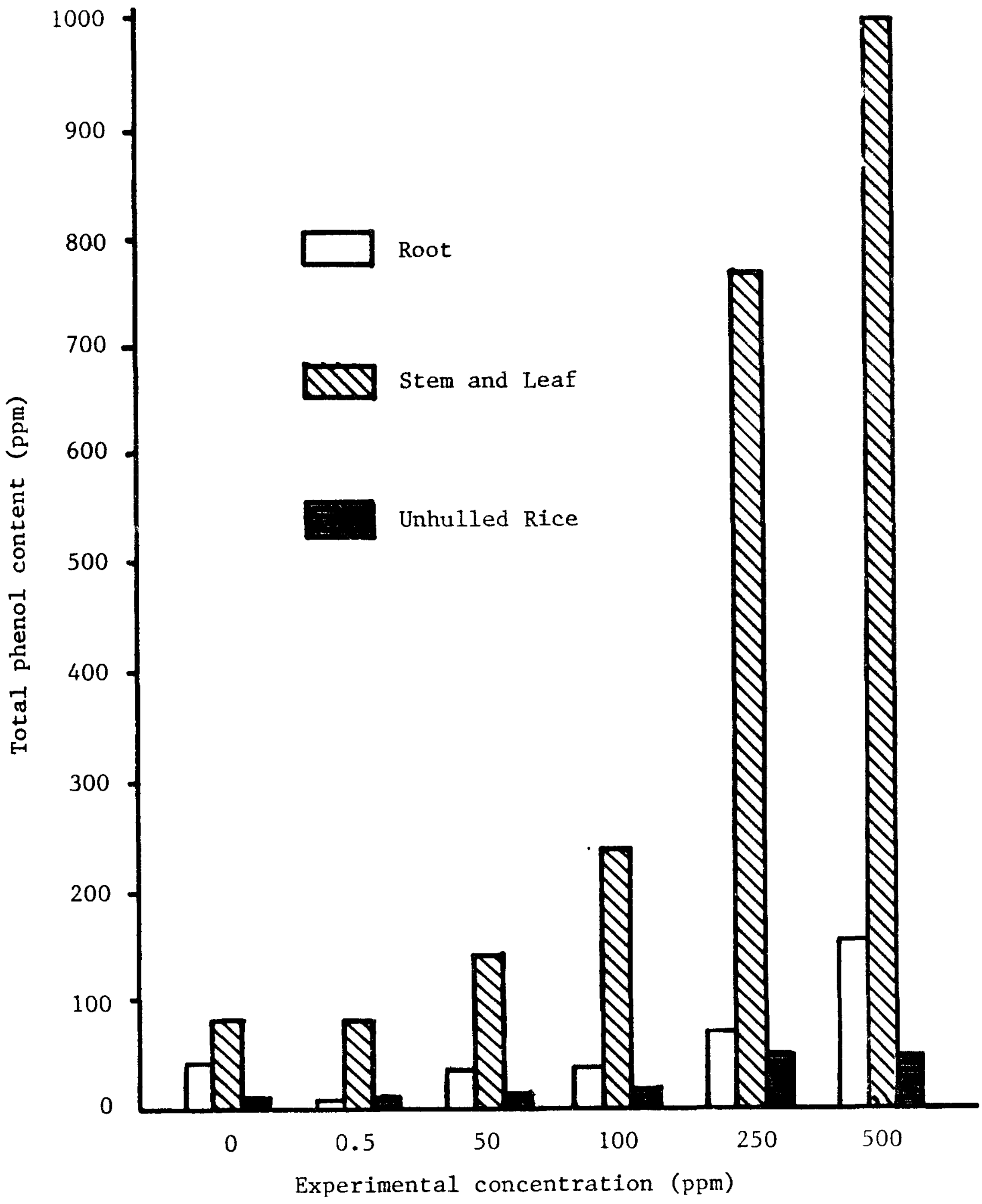

Figure 2. Total Phenol Content in Various Organs of Mature Rice Irrigated with Different Concentration of Phenol.

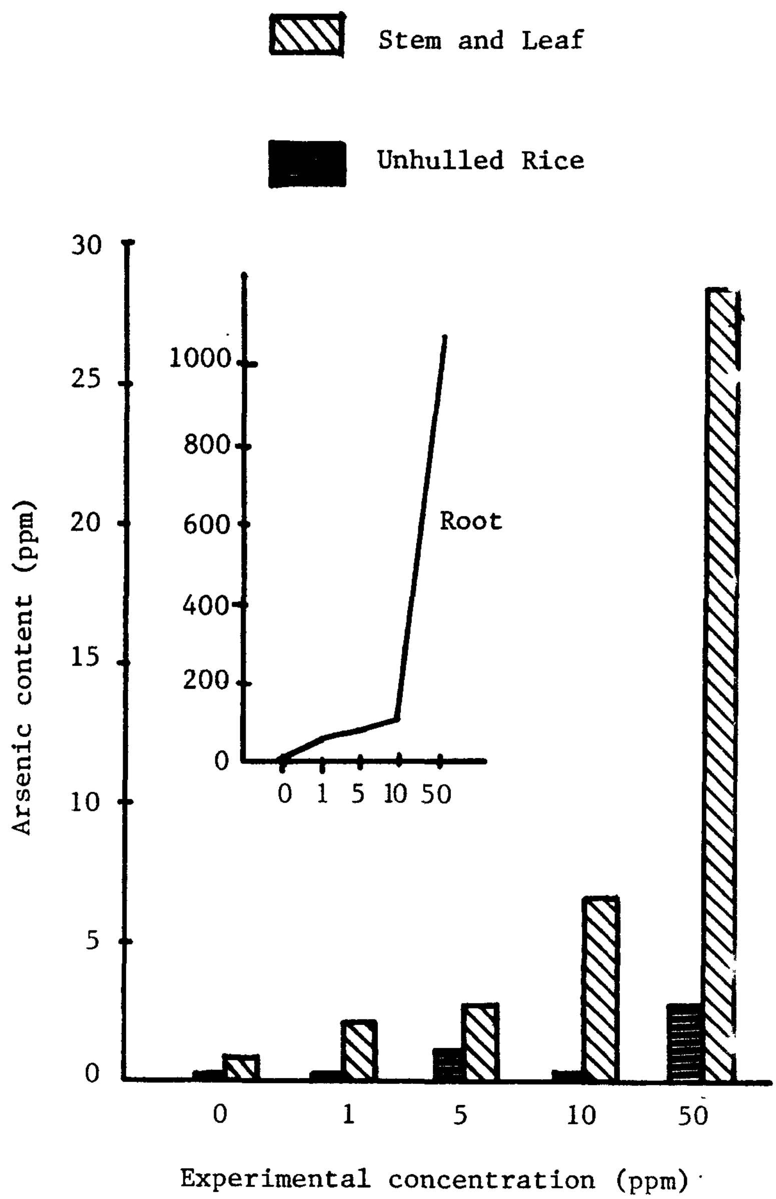

Figure 3. Arsenic Content in the Mature Rice with Different Concentration of Na_2HAsO_4.

rice. However, as the concentration rises up to 5 and 10 ppm, the growth of the wheat and rice are inhibited respectively, and the arsenic accumulation in the crops became more evident. As the concentration rose to 50 ppm, the growth of wheat and rice are heavily injured, and the arsenic content in plants increases."

In the U.S. The four common biocides used in rice culture are listed in Table 5 along with the recommended applications and the tolerances for residue on the rice grain. Brown has investigated these biocides and developed management guidelines for their use.

TABLE 5. BIOCIDES USED IN CULTURE OF RICE

Herbicides	Recommended Application (lb/acre)	Tolerance on grain (ppm)
Propanil	3.0	2.0
Molinate	3.0	0.1
Carbofuran	0.5	0.2
Carbaryl	1.0	5.0

The tolerance limits on rice are those found as residues when the recommended applications are followed. The residue is measured on a ground sample of the unhulled rice and includes the residue on the hull, bran, and grain. The grain that is eaten will contain a small part of the total residue that is measured.

Sokklov, et al., studied the behavior of several biocides in rice irrigation systems. He measured the amount translocated to the soil, rice plants and irrigation waters. Using an application of 14 kg/ha (12.5 lb/acre) of propanil, he found different amounts of the biocide in different years. Sixteen days after the applications, the rice plants contained 3% in 1972 and nearly 15% in 1973 of the initial amount of propanil applied. The concentration of propanil and its metabolite (3,4-DCA) was 25 ug/plant or less on the sixteenth day and decreased to zero in two to three months. This study shows the small amount of translocation to the whole plant with an application rate of four times that recommended in the U.S.

Jolley investigated the effects of chlorination on organic constituents in effluents from domestic sanitary sewage treatment plants. He found 32 stable organic constituents in effluents from domestic sanitary primary sewage treatment plants. Twenty-three were quantified at 2 to 190 μg/l levels. Phenol, at 6 μg/l, was the only compound found that is on the priority pollutants list. (This list contains those organic compounds suspected of being serious health hazards.) Nine stable organic constituents were identified in the effluents from domestic sanitary secondary sewage treatment plants. Eight of these were quantified at 5 to 90 μg/l levels, but none are on the priority pollutant list. After chlorinating to a 1 mg/l chlorine residual, seventeen chlorine-containing stable organic compounds were present in the effluent from a secondary plant treating domestic sanitary sewage. These seventeen compounds were quantified at the 0.5 to 4.3 μg/l levels. Two of the 17 compounds are on the priority pollutant list. These were 2-chlorophenol at 1.7 μg/l and 4-chloro-3-methyl phenol at 1.5 μg/l.

Jolley's work indicates the extremely low level of stable organic chemicals that can be expected in domestic wastewaters use in irrigation. Phenol and two chlorinated byproducts were the only compounds found which are considered to be a potential health hazard. The concentrations of these phenolic compounds were four orders of magnitude less than the level Yin-hsiao found causing an increase in the phenol content of unhulled rice grain and two orders of magnitude less than the tolerance limits for residual of several phenolic-base pesticides used in rice production. An increase of persistent toxic organic in man's food chain will not occur via irrigation of rice with domestic wastewater; however, the inclusion of industrial wastewater with biocidal contaminants above the tolerance level would need to be evaluated prior to reuse in the irrigation of rice.

Economic Feasibility

Storage - Wastewater irrigation of rice will require storage of the wastewater during non-irrigation periods. The amount of storage is a controlling economic factor.

The length of time to grow rice is dependent upon the variety planted. Very short season varieties require 120 days, while short season or midseason require 140 and 155 days, respectively. Rice may be flooded when rice seedlings are 4 to 6 inches tall, which will be 3 to 4 weeks after planting. Water is added through the growing season to maintain the depth of water between 4 and 6 inches. The paddy is usually drained about two weeks prior to harvest to allow the field to dry and accommodate mechanical harvesting equipment. This sequence of events requires use of large quantities of irrigation water over a three to four month period. In Arkansas, Mississippi, Tennessee, and Missouri, storage of 8 to 9 months would be necessary for growth of this single crop. In the southern parts of Louisiana and Texas, a second crop of rice can be produced from the stubble remaining after the first cutting. This "stubble" crop will consume another 12 inches of water and extend the water use period from 3 months to about 5½ months. Consequently, in these areas with longer growing seasons, less storage is needed.

The decline in the supply of underground water in the Grand Prairie area in Arkansas has stimulated interest in reservoirs as a means of utilizing surface water for rice irrigation. A survey made in 1958 by the Arkansas Agricultural Experimental Station shows 106 reservoirs had been constructed by farmers to store water for rice irrigation. The economic evaluation part of the survey showed that the larger reservoirs (80 to 160 acre) had less per acre cost than irrigation from wells, but that smaller reservoirs (20 to 40 acre)had costs of 10 to 35 percent higher than the costs of irrigation from wells. The major cost factor in reservoir storage was land. When waste land was available, cost savings were obtained with 20 to 40 acre reservoirs.

When using water from reservoirs, farmers usually drained their fields only once, compared with one to three times when well water was used. This drainage of the field fewer times and more rapid flooding when water was applied resulted in farmers with reservoirs using less labor, about 2.5 hours per acre, in irrigating rice.

Comparison of Alternative Land Treatment Systems - In order to determine the opportunity of wastewater irrigation of rice being cost effective, a series of calculations were made to compare the relative costs of rice irrigation, forage crop irrigation, and overland flow. Generalized design conditions were necessarily assumed to enable such comparisons. Since land treatment costs are very site-specific, the results can only suggest what alternatives should be fully evaluated in a facility plan.

The three comparison incorporated: (1) identical primary treatment, (2) different amount of storage, (3) identical transport (pipeline and pumping) cost, (4) different periods and rates of wastewater application, and (5) municipally owned storage, overland flow and forage irrigation sites but privately owned rice paddies.

Primary treatment was included to reduce solids for odor and operational reasons and to reduce pathogens for health reasons. Even though EPA will accept a minimum of comminution and screening for overland flow systems, more extensive primary systems, such as the aerated lagoon, are considered necessary by Louisiana and some other states. However, assuming the primary treatment costs to be the same is a disadvantage to the economics of the overland flow system.

The storage costs were calculated for nine months of detention for rice irrigation, two months for forage irrigation, and one month for overland flow. These storage periods for forage irrigation and overland flow are one month longer than minimum recommended by EPA for the rice producing areas. This month was added as a safeguard against infrequent operation for small treatment plants but is an economic disadvantage to both forage irrigation and overland flow systems. Because rice is grown in relatively impermeable soils on flat terrain, unlined storage lagoons and flood irrigation techniques were assumed for the three systems.

Outside of California, the rice growing areas in the U.S. have more annual precipitation than potential evapotransporation, and in these areas hydraulic loading based on soil permeability rather than nitrogen loadings is the limiting constraint in design of an irrigation system. The acreage calculations for forage irrigation are based on one inch/week over ten months of the year. The acreages for overland flow are based on an application of eight inches/week over 11 months of the year. The land values in Table 6 include 25% extra for fences, roads, and buffer zones.

An inventory showed three predominant sizes of communities in counties with large acreage in rice production. In accord with the inventory, calculations were made for populations of 1000, 4000, and 12,000.

Storage costs were determined using EPA's report, 430/9-75-003, "Costs of Wastewater Treatment by Land Application." The cost curves used are based on EPA Sewer Construction Cost Index of 194.2 for February, 1973. The costs were updated to the April, 1979 Sewer Construction Cost Index of 344.9. The storage costs include reservoir construction and embankment protection but not lining or land. The land areas for storage are calculated on: (1) 5 ft water depth in reservoir less than 10 million gallons, (2) 12 ft water depth in reservoirs above 10 million gallons, and (3) dike configuration as specified in the above report.

The design factors which highly influence the economics of these land treatment systems are storage volume and land areas for the application site and the storage lagoons. A tabulation of these items are shown in Table 6.

TABLE 6. COMPARISON OF THREE LAND TREATMENT SYSTEMS

Items	Populations 1000	4000	12000
Million gallons/year	25	100	300
Capital Cost of Storage ($1,000)			
9 months	71	248	604
2 months	51	87	195
1 month	37	73	124
Land for Storage (Acres)			
9 months	7.2	23.8	65.5
2 months	3.8	6.5	16.5
1 month	2.5	6.9	9.1
Land for Application (Acres)			
Forage Irrigation @ 1"/wk	25	100	300
Overland Flow @ 8"/wk	3	12	37
Differential Acres (Forage Irrigation area & storage - 9 month storage)	7.6	27.7	81.
Differential storage costs (9-2 months) ($1,000)	20	161	409
Differential storage cost per differential acres ($1,000/acre)	0.9	1.9	1.6

The capital costs for storage are shown for three population levels and three storage periods. The land required for these nine storage ponds is tabulated as is the land for forage irrigation and overland flow application sites.

These economic evaluations of storage and land requirements for rice irrigation, forage irrigation, and overland flow indicate the overland flow system will have the least capital costs. The economic comparison shows similar capital costs between a municipally-owned storage and forage irrigation system and a system with privately-owned rice irrigation and municipal storage facilities.

The overland flow system is likely to have considerable economic advantage over rice irrigation with wastewater. The land requirements for one month of storage plus the application area is less than the land needed for nine months of storage for rice irrigation. Nine-month storage is two to five times more costly than one month. This differential in capital cost for storage is equal to about $12,000/acre to shape and plant the land and provide an overland flow distribution system. Use of an overland system will also depend upon permit limitations, soil characteristics, slope of the land, and transport distances. These are all site specific and cannot be evaluated in these calculations.

Where an overland flow system is not feasible, forage irrigation will be economically competitive to rice irrigation. In the rice-growing areas, it is likely that forage irrigation will be done on municipal purchased land. Forage irrigation can be managed to minimize disposal cost without damage to the environment, but the crop selection may not maximize the cash returns from the land.

The differential in land requirements needed for forage irrigation (areas for application plus 2 months of storage) minus the land needed for nine months of storage with rice irrigation are shown in Table 6. The differential in cost for 9 months over 2 months of storage are also shown. These differentials show the cost for additional storage needed for rice irrigation is equal to between $900 and $1,900 per acre of additional land needed for forage irrigation. These amounts are sufficient to purchase land in most ricegrowing counties. There are several site-specific factors which must be included in this comparison prior to concluding that forage irrigation will be the cost-effective system. The major ones are purchase of the water or storage by the rice farmer, forage crop revenues, operating, and maintenance costs and differences in transportation distances.

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