WATER MANAGEMENT

Most California rice is produced by direct seeding into standing water with permanent flood for most of the season. Limited acreage is drill seeded which also uses a permanent flood after stand establishment. The origins of this system have much to do with weed control, nitrogen management, and productivity, discussed in other sections.

Typically, a shallow flood is established over the field and pre-germinated seed is sown by airplane into the water. The seed comes to rest on the soil surface and establishes in that spot. The water is kept on the field throughout the season except for short-term drainage, permanently removing it only at the end of the growing season to prepare the field for harvest. Rice growers spend much of their time managing the water and there are numerous variations on this simple theme which makes water management more complicated than it first appears. A previous section dealt with leveling and water management structures. This section deals with water management during the season.

Purposes of Water Management

The general goals of water management are:

- Supply water to the crop
- Establish an optimum plant population
- Suppress weeds
- Provide for pesticide applications
- Conserve nutrients
- Protect against cold weather
- Protect water quality
- Manage salinity

Each will be discussed later in the chapter.

Seasonal Water Use

Seasonal water delivery for California rice varies a great deal depending on soil type, management, and seasonal length (Table 1). The average delivered use is approximately 5 to 5.5 acre-feet per acre (af/a), but varies from about 4 to 8 af/a, or more, depending on soil properties and water management.

Evapotranspiration (Et, crop use, consumptive use) is the amount the crop itself takes up through the roots and transpires from leaf surfaces into the atmosphere. Et varies with seasonal length, so an easy way to save water in rice is to grow shorter season varieties. There is also some seasonal variation in Et due to annual weather fluctuations and differences due to planting dates. The climatic factors important to crop use are solar radiation, wind, and temperature.

Percolation is controlled by soil texture and impervious subsoils. Most rice soils have clay and/or hardpan in the subsoil, so water does not percolate rapidly compared to deep loamy or sandy soils. In general, percolation losses throughout a growing season in California clay soils are less than 4” per growing season. If deep per-

Table 1. Approximate seasonal water use by use component for rice in California. Note, this table does not account for leaks in levees and outlets.

Seasonal Water Use	Acre feet per acre
Evapotraspiration (Et)	2.75 - 3.25
Percolation/seepage	0.2 – 1.0
Drainage	0 - 2.0
Total	2.95 – 6.25

colation is excessive, rice may be a poor crop choice. In New South Wales, Australia, where water shortage is chronic, rice soils are tested for infiltration rate, and if excessive, rice cannot be grown.

Seepage is the lateral movement of water out of the field, usually through levees. Seepage occurs in all soils but is more of a problem in course textured soils which have high hydraulic conductivity. Seepage rates are also determined by the height of water on the other side of the levee. Seepage is lower (or even reversed) when there is a water supply canal or another flooded rice field on the other side of the levee. Studies have shown that seasonal water losses due to seepage are less than 2” per growing season.

Drainage during and at the end of the season accounts for the balance of delivered use. This number has gone down with the widespread use of laser leveling, which allows for less spillage, and mandated water holding required for pesticide use.

Water Management Systems

Different water management system designs are used for ease of management, water conservation, and maintenance of tailwater quality. Each is discussed below.

Flow Through System

The most common system is the flow-through system, also called the conventional system. Water supplied to the topmost basin sequentially floods each successive basin as it makes its way to the lowermost basin. The water is regulated by weirs or rice boxes. Excess water is allowed to spill over the last box into a drain. By continually supplying water to the top, and allowing a small amount to spill out the bottom, with the boxes adjusted properly, the water level is automatically maintained, hence the name “flow-through system.” The advantages of this system include low installation cost, the ability to flush salts from the field, easy installation and removal, and adaptation to irregular slopes. The disadvantages include substantial management, difficulty in preventing excess water in lower basins, and slow response to adjustments. This system is not well adapted to holding water as required by regulations (discussed later in this section). Holding water is contrary to the intended purpose of the system. Figure 1 is a schematic of a conventional flow-through system.

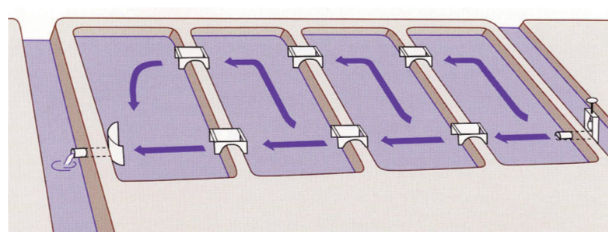

Figure 1. Conventional flow through system showing serial application of water from top (right) to the bottom of the field (left). Double box system reduces restrictions on water flow and may improve circulation. From: Hill et al. 1991.

Recirculating Tailwater Recovery System.

These systems capture tailwater in a sump and pump it back to an inlet for reuse in the same or other fields. They are useful for water conservation and keeping pesticide residues out of public waterways. Numerous recirculation systems have been installed although many have fallen into disuse because of maintenance and operation cost. These systems are adaptable to single fields, whole farms, and whole irrigation districts. Only a few single-field systems are in use. Figure 2 is a schematic of a single field with a recirculation system. The concept applies to various scales. All systems in use help stretch the limited supply of expensive water and allow growers to comply with less restrictive holding requirements. In-field water management is the same as for the flow-through system. The major management challenge is balancing the intake

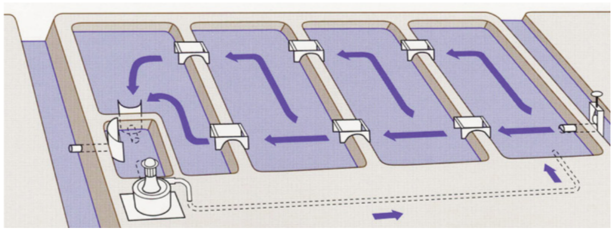

Figure 2. Single field recirculation system. This concept can be scaled up to multiple fields, multiple farms or whole irrigation districts. From: Hill et al. 1991

of fresh water with recirculated water, which is more difficult as the system increases in size. The advantages of this system are the ability to keep pesticide residues out of public waterways, good flexibility of management relative to regulations, reduction of cold water effects, conservation of water, and lower water expense. Disadvantages are the cost of installation and maintenance, extra land out of production, and a higher level of management.

Static Water Irrigation System

This system was developed specifically to keep pesticide residues out of public water. The key features include multiple water inlets from a canal along the side of the field so that each basin is irrigated in parallel but separate from the others (Figure 3). The inlet acts as the drain at the end of the season and the goal is for zero drainage. Some saline fields have convention-

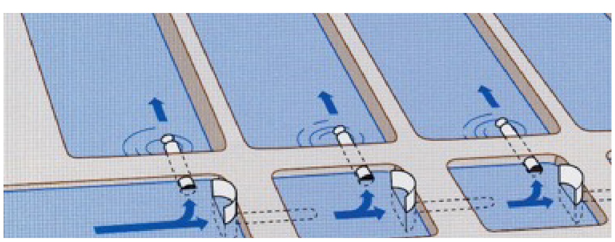

Figure 3. Static water irrigation system. From: Hill et. al.,1991

al drains at the end opposite the intakes which allow for flushing of salts at the start of the season. Once water goes into the field it stays until the end of the season, with additional water added as needed. To accomplish this, inlet pipes are installed below grade at the low side of each basin. Each pipe has a flap valve that is opened by the pressure of inflowing water, and closes as the inflow declines, keeping water in the field. Water levels are managed by changing the levels in the supply ditch. Opposite each inlet pipe is an in-ditch weir to adjust water levels. To drain the basins, water in the supply ditch must be drained and the flaps opened. Advantages include an excellent capability for water holding, water conservation, independent control of levels in each basin, easier management, and no need for a return pump. Disadvantages include higher cost of installation and maintenance of the system, land out of production, reduced flushing of salts, and the unsuitability of permanent installations for rotation crops (although temporary static systems have been used in row crop areas).

Cold Water Effects

It is common knowledge that yields are low near a cold water intake. Re cent research has shown that the cold water and the associated reduction in rice productivity extend well beyond the area where the effects are readily visible. The distribution of cold water can extend throughout the intake check and bleed into the adjacent check (Figure 4). The infrared image taken in early June showed that the water temperature warmed by only about 5 degrees as it passed through the 15-acre check. The intake water temperature was 56° F when it entered the field. Plant development throughout the growing season was delayed as a result (Table 2). Interestingly, the gradient in developmental delay was accentuated with time. For example, there was an 11-day difference in the time to first tiller between the cold and warmer parts of the check. The differential increased to 21 days by panicle initiation and 32 days at boot. The cold water effects are accumulative. Similar relationships were observed in the yield components (Table 3). Head size and seeds per panicle decreased

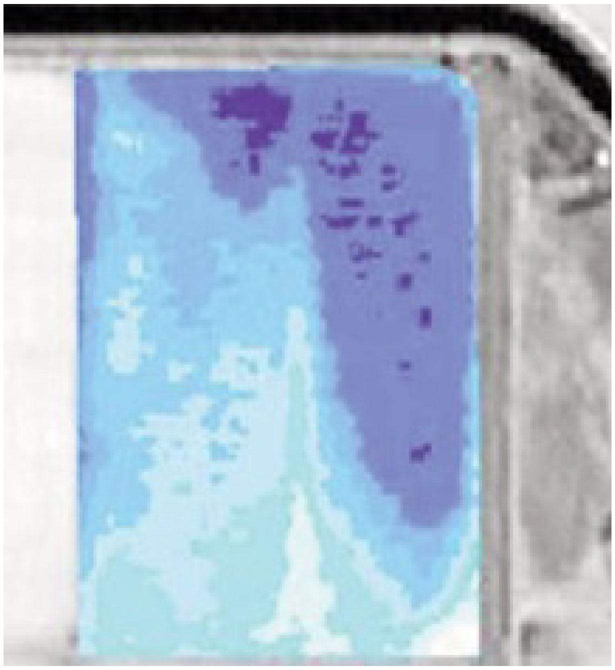

Figure 4. An infrared image showing the water temperature gradient in an intake check in early June 2001. In coming water = 56° F. There a temperature gradient of about 5° F across the check.

from the warm to the cold areas of the check. There was a corresponding increase in blanking and a reduction in yield. Notice that the yield loss is not restricted to just the area surrounding the intake box. It appears that the potential yield reduction due to cold temperature is comparable to a dose-response function.

In that, the longer the crop is exposed to cold water the more pronounced the impact. Figure 5 uses a threshold water temperature of 65° to illustrate the concept. The longer the plants were exposed to water temperature of less than 65° during the day for the first six weeks the greater the yield loss. For example, only 20 percent of the yield potential was observed in the areas of the field that experienced water temperature under 65° for 250 hours (i.e. 80 percent reduction). In contrast, at 150 hours of exposure, 60 percent of the yield potential was realized. If you farm ground with cold water, you may want to consider modifying the water delivery channel when laying out your irrigation system to minimize this effect.

Flow Rates

Flow rates determine the speed of initial flooding and, if necessary, re-flooding. Speedy flooding is desirable for earlier planting and to prevent weeds and other pests, such as seedling disease, shrimp, and midge, from getting ahead of the rice. Precision leveling, flat fields, and corrugated rollers have made initial flooding quicker compared to earlier years, given simi-

Table 2. Days after planting (DAP) to reach different stage of development in a cold water intake check.

	1st Tiller	PI	Boot	50% Heading
	-------------------------------- DAP --------------------------------			
North	43	85	120	---
(inlet)	34	69	104	114
	31	64	90	104
South	32	64	88	96

Table 3. Yield components as effected by water temperature gradient across an intake check.

	Head (cm)	Seeds per panicle	% Blanks	Yield (lb) @ 14% MC
North	14	0	98	402 (green)
(inlet)	13	10	53	2288
	16	45	29	5924
South	17	53	12	9138

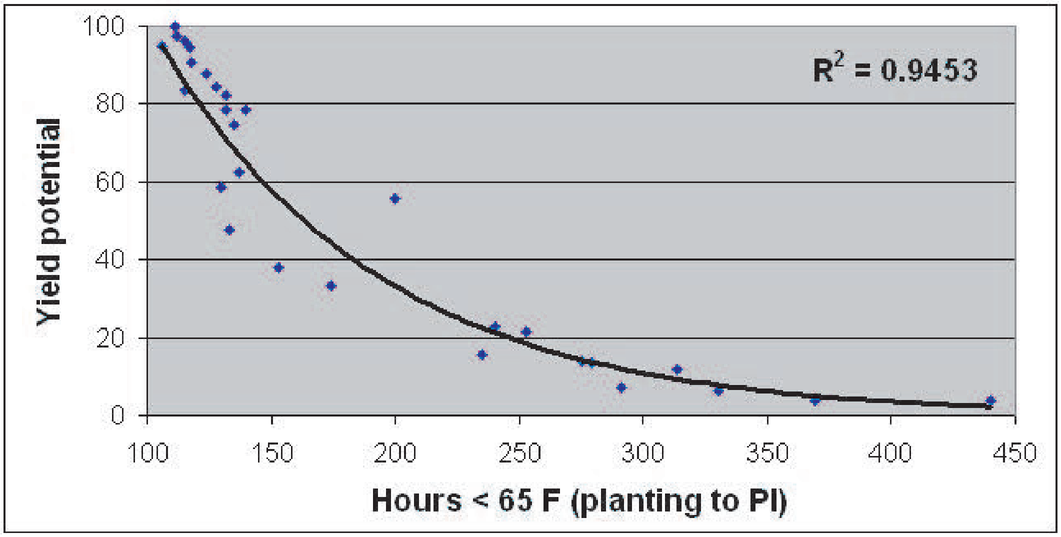

Figure 5. The potential yield reduction in rice when exposed to water temperatures < 65° F for different periods of time.

lar flow rates. Increasing competition for water and greater reliance on pumps may reduce flow rates in the future, so it is important to have an appreciation for what is needed for the various stages of crop production.

Flow rate guidelines appear in Table 4, and can be used to estimate the time to flood with a given quantity of water or the desired flow rate for a given size field. The calculations in Table 4 are for a delivery of four acre-inches per acre, which assumes that this is sufficient to just cover the field for seeding, but not to establish a depth of flood water. About two inches are assumed to go into the soil and the balance will be on top. The amount required for initial flooding is really quite variable and depends on the amount of water already stored in the soil, the slope of the field and how the grower floods. 'Acceptable' flooding times are in the shaded area and are selected to help avoid problems that develop with increasing time. During cool spells, a longer flooding period may be acceptable because growth of pests is slower. Acceptable time is arbitrarily set at 96 hours in Table 4, although it is not a disaster if the field takes a day or two longer to flood. When fields take longer than a week to flood, pest problems start to increase.

Putting it in simple terms, quick flooding requires roughly 28 gallons per minute per acre (gpm/a). Once a flood is established, the amount needed for maintenance is much less, a continuous flow of 5 gpm/a over the course of a season is usually adequate. For design purposes, one should plan on a minimum of 10 gpm/a. The extra capacity allows electric pumps to operate during off-peak periods. Extremely low flow rates may require special management, such as sowing rice in sections of the field as they are flooded, or dividing fields into small units.

Water Management Methods

Initial Flood

When field preparation is completed, boxes installed, and levee ends closed, water is introduced into the top of the field. Additional inlet sites may be used in large fields to speed the process if sufficient water is available. Flow rates determine the rate of flooding. The objective in the initial flood is to get the entire field wet as quickly as possible. In a flow-through system, this may be accomplished by blocking back water in the top basin until it is nearly cov-

Table 4. Approximate hours for initial flood for various field sizes with different flow rates. Shaded area represents acceptable time. Based on delivering 4 acre inches/a.

	Size of Field in Acres			
GPM	**50**	**100**	**150**	**200**
500	181	361	542	722
1000	90	181	271	361
2000	45	90	135	181
3000	30	60	90	120
4000	23	45	68	90
5000	18	36	54	72
6000	15	30	45	60
7000	13	26	39	52
8000	11	23	34	45
9000	10	20	30	40
10000	9	18	27	36

ered by setting the board in the first box to hold the minimum amount and allowing the rest of the water to spill over. Repeat this basin by basin until the last one is covered. It is not necessary to establish final depth at this time, only to get the soil wet to receive the seed. It may take several days to establish the desired depth, but it is not necessary to delay seeding. Flooding from the top of the field helps flood the field faster. If the boxes are all wide open during initial flooding, the water will tend to run straight to the lowest basin, and one must work from the bottom of the field to the top. This is called back flooding and takes much more time because the tendency is to get more water than needed in the lower basins. Increasingly growers are establishing shallow ditches between rice check boxes which allows the checks to flood more uniformly.

Establishing a Stand

Following seeding, the goal of early season water management is to establish a vigorous, healthy, weed-free stand. The management of water during this period is integrated with herbicide use and greatly affected by water supply. For example, early applied foliar materials, such as Clincher, require a drained field. Rapid reapplication of water is important for good weed control and may affect success in some areas because of low flow rate. For materials applied into the water, such as Bolero, the goal of water management is to quickly establish a continuous flood of 4 to 5” which provides a good compromise between rice growth and weed suppression. Shallow water (1-3”) promotes rice growth and root anchorage but also favors weed growth. Deep water (7-8”) delays early rice growth and tillering, but also greatly inhibits grasses and smallflower umbrellasedge, the most competitive weed species. Water management for specific herbicides is discussed in the section on weed management.

Drainage for stand establishment

Many growers use a planned drain period after sowing to help improve stand establishment. This practice is known as the ‘Leathers method,’ after the grower who popularized it. This is a useful practice where rice has difficulty anchoring to the soil or is easily covered or moved during windy weather. When properly used, stand density and uniformity of distribution is usually improved and concerns about the effects of wind are less. Generally, fields are completely drained immediately after sowing and the water is left off until the radicle penetrates the soil and anchors the seedling. In this aerated situation, roots are stimulated to grow more than they are in a flooded, less well-aerated environment. Seedling rice responds to a surplus of air by increasing root growth, while shoot growth is less stimulated. The sequence of events is:

- Sow rice into shallow flood;
- Drain field rapidly and completely, immediately after sowing up to two days after sowing;
- Maintain drained condition for 3 to 5 days, depending on temperature and growth of roots
- Reflood when radicle penetrates soil

This practice must be used only where there are enough outlets for quick drainage and there is an adequate water supply for quick reflooding. Furthermore, the field should be well-leveled so that it will flood and drain quickly. If the field takes too long to drain and reflood, drought stress may kill some of the seedlings and result in a poor stand in portions of the field. Internal drains, either across the basins or around their circumference, help speed water removal and application. Timing of drainage relative to planting is also important. Waiting for more than a day or two reduces the beneficial effects and may jeopardize weed control operations and timing.

Early season water management and weed control: Delayed Pinpoint Flood

While it may be desirable to maintain a 4-5” of water on the field early in the growing season to control weeds, some herbicides (particularly foliar herbicides) require lowering the water in the field to expose weeds and maximize herbicide contact with weeds. This is discussed in more detail in the weed control chapter. The main point of this chapter is that during the first month and a half of the growing season, water management is often driven by herbicide (and other pesticides) use. The usage of these chemicals affects water height in the field, when water is flowing into the field as well as imposing strict limits on when water is flowing out of fields due to water holding periods (discussed in more detail later). When possible, quick removal of water and replacement after spray application is desirable for good weed control. A prolonged drain period promotes weed growth and delayed reflooding may reduce herbicide efficacy.

Alternate wetting and drying (AWD) and mid-season drain

Keeping rice soils permanently flooded has been recommended as a good practice for ensuring optimal weed control and efficient nutrient use efficiency (particularly for nitrogen). However, keeping a field flooded alters soil chemistry and makes the soil anaerobic (without oxygen). While this may be good for conserving nitrogen, anaerobic soils also produce and emit more methane (CH4) and make some heavy metals such as arsenic (As), mercury and lead more bioavailable. Thus, continuously flooded rice fields have higher CH4 emissions and higher concentrations of As (and other heavy metals) in the rice grain compared to fields that are not continuously flooded. Importantly, while California rice fields are high emitters of CH4 (due to water seeding and straw incorporation), the levels of As in the grain are relatively low compared to other areas where rice is produced.

One practice to reduce both CH4 emissions and grain As concentrations, is to let the field dry out one or more times during the growing season. This introduces oxygen back into the soil and can lead to reduction in CH4 emissions of over 40-60% and a reduction in grain As of 30-40%. However, doing this must be done carefully, otherwise there is the risk of yield reduction, fertilizer N losses and high nitrous oxide (N2O) emissions (a more potent greenhouse gas than CH4).

The term alternate wetting and drying (AWD) is used very broadly and covers a wide range of practices where the soil is allowed to dry down (become aerobic) at least two or more times during the season. A mid-season drain is a single drain during the season. Using AWD practices in California rice systems is not very practical because it is hard to find time during the season to implement multiple drains without affecting crop productivity. For example, during the first month or so, water management practices are largely driven by weed management decisions. Furthermore, letting the soil dry during this period will result in fertilizer N losses and N2O emissions because there is a lot of fertilizer N in the soil at this time. Secondly, we do not recommend drying the field during booting as this can lead to blanking if nighttime temperatures get too cold (in fact, we recommend raising the water during this time). Draining during the grain fill period is likely to result in negative grain quality issues. This leaves a window of opportunity during the mid-season for a single draw-down of water. We call this a mid-season drain.

A mid-season drain

Many growers in California apply propanil during the mid-season (30-50 days after planting) as a clean-up herbicide. Propanil is a contact herbicide, so flood water needs to be lowered. A mid-season drain could simply be an extension of this drain. Our research has shown that a short dry-down period (2-3 days) lowers CH4 emissions for a short period but emissions increase again after field is flooded. When the drain is extending to 8-12 days (time depends on the field), CH4 emissions do not increase rapidly after the field is re-flooded and CH4 re-

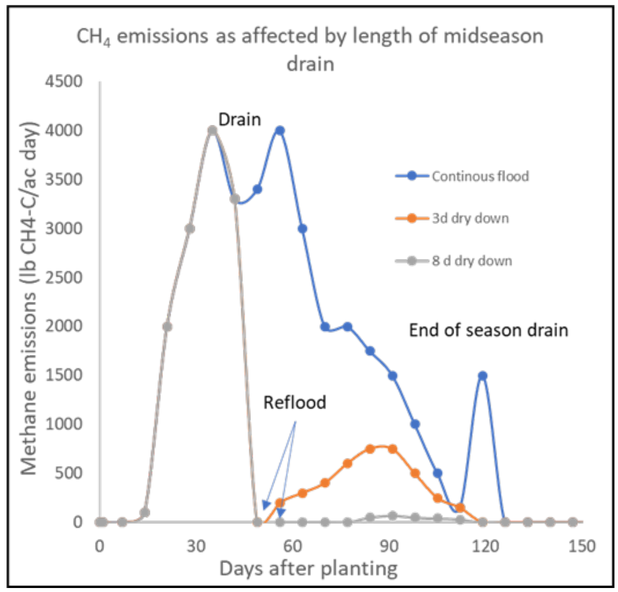

Figure 6. Example of CH4 emissions from continuously flooded fields vs a short or long mid-season drain.

Table 5. Methane emissions and rice grain yields from 2018 trial at the RES comparing continuous flood to a 5and 12-day mid-season drain period (Source: Perry et al., 2022).

Treatment	Methane emissions CH_4-C (lb/ac)	Grain yield cwt/ac
Continuous flood	136	93.5
5 d drain	84	92.4
12 d drain	49	92.7

ductions of 40-60% can be achieved Figure 6. We have done this research for close to a decade and on a number of fields and have found no yield reduction Table 5.

Here are some do's and don'ts:

- Don't let soil dry out during the first 5 to 6 weeks of the season. There are several reasons for this:
  - First, is that in water-seeded systems where the N fertilizer was applied pre-plant, this fertilizer is in the soil until roughly 6 weeks (the rice takes most of it up between 4 and 6 weeks after planting). Letting the soil dry during this period will result in potentially high N losses (nitrification and then denitrification when field is reflooded).
  - Second, due to nitrification and denitrification, high amounts of N2O will also be emitted.
  - Third, before this time the canopy has not covered, thus there is the potential for more weed growth.
  - Finally, early-season drains tend to extend the time a crop takes to reach maturity.
- Ideally, start the drain around 35 to 40 days after planting. This results in fields being reflooded around 45 to 50 days faster planting. By this time, all of the N fertilizer that was applied early in the season has been taken up.
- If you are applying a top dress of N fertilizer, apply it just before reflooding field.
- Monitor field during drain period. In considering the total drain time, account for the time it takes to reflood field.

One question that often arises with this is if this practice conserves water. In a typical year where rice is planted at normal acreage, the savings of this practice is small (about 1 inch we estimate). The reason for this is that most percolation and seepage water losses are very low when a lot of rice is in the landscape. This is because the water table is high. However, when rice is surrounded by fallow fields, upland crops and farmers using well pumps, the water table is lower. Growers often report using a lot more irrigation water in these fields just to keep them flooded. In these situations, having no flood water on the field for a period of time will save more water.

This system can also be used for dryor drill-seeded rice as is done in the mid-south. In this situation, fields are usually fertilized then flooded about 4 weeks after planting. In order to ensure all or most of the fertilizer is taken up, the field should remain flooded for at least two weeks before the dry-down period is started.

Permanent flood, water depth effects

A permanent flood should be established as soon as possible after sowing. The sooner it is done, the more beneficial impact it will have on weed management. Once established, permanent flood is maintained throughout the rest of the season. Maintain a steady depth of 4"-5" through maximum tillering and avoid taking water off the field.

The goal of the permanent flood is to maintain steady pressure on weeds and optimize rice growth. Rice growth response to various depths is demonstrated in Figure 7. Rice growing in shallow water (1-2") begins tillering faster and reaches a higher maximum tiller number earlier than rice growing in medium (4-5") or deep water (7-8"). Rapid establishment of plant cover is the main reason many growers prefer shallow water early in the season. Ultimately, the final tiller number is similar at all depths within this range because excess tillers developed in shallow water die off to a level that the plant can support. Leaf development and plant size (biomass) follow a trend similar to tillering. However, rice plants in deep water tend to be taller and mature earlier com-

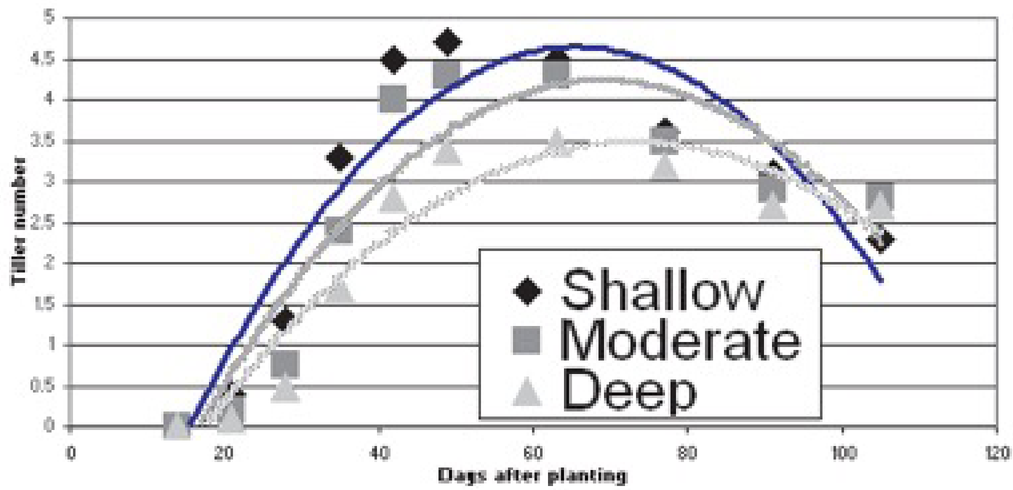

Figure 7. Tillering of M-202 rice at three water depths held season long, 1986. (Williams et al. 1994)

pared to rice growing in shallow water. Growth of rice in deep water suggests it is under stress which slows growth for the first half of the season, even though final growth parameters, except height and maturity, are similar at all three depths. Yield in field-scale trials comparing different depths within the range of 2" to 8" was the same across all depths.

Most growers are reluctant to accept slower crop development and increased management required for deeper water and prefer lower water to ensure that plants perform at their optimum, particularly when environmental conditions are adverse. Some soils, such as alkaline and saline soils, are already stressful to the crop, and deep water is not advisable. In addition, levees holding deep water are more subject to wind damage. The use of some herbicides in deep water is also not advisable. However, some growers have found value in deeper water, 5-7" through tillering, for better weed control where soil conditions permit it. One should avoid very shallow water, 1-3", because weed control will be difficult.

Blanking Protection

Blanking occurs when pollen is damaged by cool temperatures (55-60°F, depending on variety). It is the major temperature-related factor reducing yields in California. It is a potential problem in all areas of the valley but the problem increases as one moves south due to cooler night-time temperatures. Since rice florets are primarily self-fertilized, the loss of pollen is not usually replaced from other nearby florets, so a kernel does not develop. UC research in the early 1970s showed that the position of the panicle when it is sensitive to cool temperature is low in the stem, partially underwater. This is usually 10-14 days before the panicle emerges, and when the collars of the flag leaf and the penultimate leaf are aligned. The sensitive period lasts for about a week for any individual panicle and about three weeks for a field. As the air cools during the night, the air temperature within the canopy also drops. However, the water resists change and its temperature takes longer to drop. The higher water temperature can provide a critical source of heat to protect the rice heads from cool temperature damage. The change in

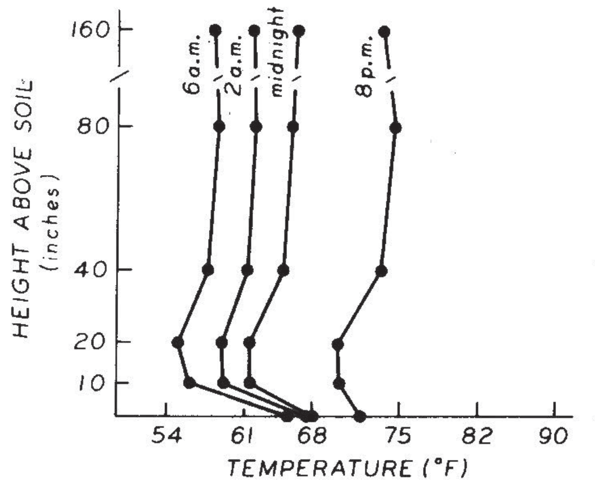

Figure 8. Temperature profile of a rice canopy. Water depth is 6". From: Board and Peterson 1980.

air and water temperature at different heights above the soil is shown in Figure 8. At 8 pm, the air and water temperature are similar, but by 6 am, there is a large difference. The amount of difference increases with the depth of water and lower temperature. Growers can take advantage of this natural heater by increasing the water 7 to 21 days before heading. The water should be as deep as the levee system in the field will allow, but at least 8". This depth will partially cover the developing panicles and help protect them from the cooler air above. Since tillering is complete, water depth will not affect growth.

Pre-harvest Water Management

Preharvest drainage requires a compromise between the conflicting needs of harvesting equipment and crop ripening, although certain risk factors can be identified to guide the process. As with many other management practices, the grower's task is to optimize drain timing.

Typically, water is removed two to four weeks before the anticipated harvest date. Heavy harvesting equipment requires firm soil so it will not cause deep ruts and/or get stuck in the mud. Mud during harvest not only decreases efficiency but may also cause serious damage to valuable equipment and rut the field. The exact timing, to ensure firm soil, depends on:

- surface drainage-accurately leveled fields drain more completely than those with low spots;
- the internal drainage of the soil-soils with deep profiles usually drain quicker although soils with very high clay, such as Willows clay, are slow to drain;
- physiological activity of the rice plants that remain greener will use more moisture than senescent plants; Quadris sprayed fields tend to hang on longer and affect drain time;
- and climate during the drain period--high temperatures and north wind increase evapotranspiration.

Integrating these factors is more art than science and there is no substitute for experience in a particular field. In the end, you want a firm, but not dry, soil surface on which to run harvest equipment. In recent years, many growers have switched from half-track and full-track equipment to rubber tires, increasing the importance of firm soil at harvest.

As important as making sure the ground is dry enough to support equipment is to make sure it is moist enough to finish the crop. Premature drainage will impede ripening and result in more chalk and light kernels. In addition, research has shown that milling quality is improved if the water is left on longer, including up to the time of harvest! Since harvesting in the water is not a practical option, the grower has to decide when to drain to optimize ripening. Rice does not ripen uniformly, especially in different parts of the field, so assessing the entire field is important. The same factors that govern how fast the soil drains pertain to the moisture supply for ripening. Some rough guidelines for determining when the crop is sufficiently ripe to tolerate drainage are:

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- grains have filled from the top to the bottom of the panicle;
- color has changed from green to golden;
- tip kernels have become hard;
- lower kernels will have soft dough but not milk.

Water Stress

Drought stress sometimes occurs when a pump shuts off or is on the high side of a poorly leveled field. Some organic growers also use mid-season drainage for weed control which induces drought. Rice grows well under flooded conditions and most varieties that have been bred for flooded conditions are not very tolerant of water stress and yields will be reduced when subjected to water stress. That said, several recent studies on-farm and at the RES (specifically to look at the effects of drying a field briefly to lower arsenic uptake and reduce methane emissions) have demonstrated that yields are not reduced when the soil water content is lowered below saturation between 45 and 55 days (just before PI) after sowing. In these cases, water has been off the surface of the soil for up to eight days.

Signs of water stress include leaf-rolling, leaf-scorching, impaired tillering, stunting, delayed flowering, spikelet sterility, and incomplete grain filling (Yoshida 1981). Drought avoidance is important during expansive growth beginning in the early vegetative stage, the degree of injury from which is related to the intensity and duration of the water deficit (Hsiao 1982). However, if not severe, the addition of water usually leads to complete recovery. The most drought-sensitive growth stage is floral development, starting with microsporogenesis through heading (Boyer and McPherson 1976). Drought stress during this stage leads to blanking and the crop cannot recover from it. During ripening, premature removal of water may lead to incompletely filled kernels and lower test weight.

Managing Salinity

Rice is particularly sensitive to salinity during the seedling and pollination stages. While most irrigation water used on rice in California has low salt (<0.7 dS/m), some water sources that include drain and well water can go much higher (Scardaci et al. 2002). Sacramento River water is low in salt being between 0.13 and 0.37 dS/m.

The type of irrigation system and pattern of flow also affects salinity. In static and conventional systems, salinity increased with distance from the inlet and in areas where water stagnates (Figure 9). Water with much lower salinity will result in higher salinity as salt accumulates and moves through the field so that lower basins typically have higher salinity, which peaks during holding periods. Yield reductions were

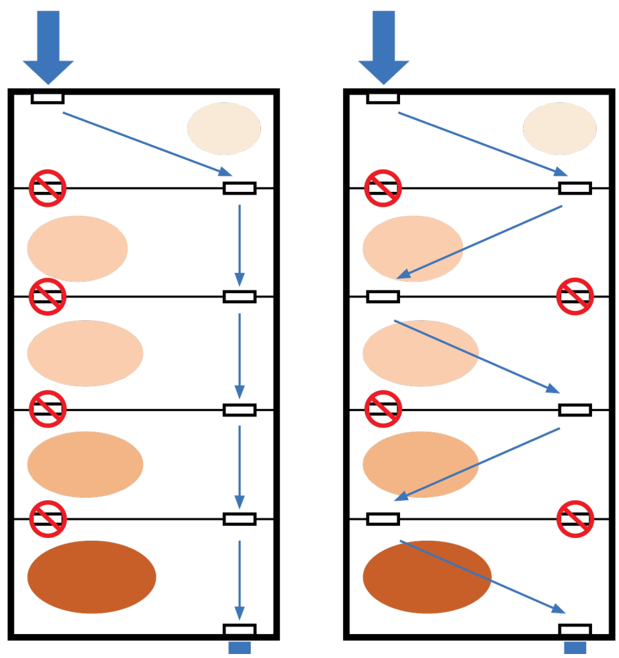

Figure 9. In the diagram above, the left shows a field with water running down one side of the field and how flood water salinity is concentrated on one side of the field (darker colors indicate higher salinity). By changing the water flow path in this field (shown on right) the water flow path is forced through the high salinity areas and helps flush them out.

associated with salinity of >0.9 dS/m .

Below are some steps to consider in order to control salinity:

- Irrigation water should have an EC below 0.6 dS/m – for an averaged-sized field this will help ensure that the field water salinity does not increase beyond the 0.9 dS/m yield threshold at the bottom of a field.
- Change water flow path – Salinity builds up in stagnant parts of the field. Changing water flow path will reduce salinity hot spots from developing (Figure 8).
- Early in the season when salinity is highest, allow for spillage and maintain higher water levels – This may not be possible in drought years or with certain herbicide programs.
- Smaller fields and multiple side inlets – The distance water travels in a field largely determines the build-up of water salinity. Larger fields will have greater water salinity build-up in the bottom of the field. Smaller fields and multiple inlets should be considered in fields with saline soil or receiving irrigation water high in salinity.
- Herbicide selection Growers using saline water should avoid using herbicides that require long-term holding so they can flush the field during the early part of the season.

Maintaining Water Quality

How one manages water not only impacts the growth of rice but also water quality. Since rice tailwater ultimately flows back to public waterways, growers must maintain its quality by using appropriate practices. Chapter 11 on water quality discusses these issues.

References:

1. Scardaci, S.C., Shannon, M.C., Grattan, S.R., Eke, A.U., Roberts, S.R., Goldman-Smith, S., Hill, J.E., 2002. Water Management Practices Can Affect Salinity in Rice Fields. Calif. Agric. 56, 184-88.