

Irrigation Research and Development
in Hawaii, Utah and California.

BS150S: Study Tour Report
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1. INTRODUCTION

This report provides a brief overview of a study tour undertaken to visit government, university and private organisations in Hawaii, Utah and California over a three week period during April 1996. The study tour was conducted primarily to view the research being conducted and the extension practices employed for drip and furrow irrigation in each area. Both of these irrigation practices are receiving increased attention within the Australian irrigation industry as economic and political pressure is applied to improve irrigation efficiencies and water management. In each case, the organisations visited have been instrumental in conducting much of the pioneering work in either surface or drip irrigation and are still actively involved in research and development of management practices. While there were specific reasons for visiting each organisation, they were also selected to ensure that a diversity of environmental constraints, cropping practices, irrigation systems and research philosophies were encountered within the tour.

In Hawaii, the main emphasis for the visits was on the drip irrigation of sugarcane, while in Utah it was the evaluation and management of surface irrigation systems. Utah also provided the opportunity to discuss the future development of the surface irrigation model (SIRMOD) evaluated as part of the Sugar Research and Development Corporation funded project "*Increased productivity through better design and management of irrigated canefields (BS90S)*". California provided a diversity of crops and irrigation management practices with researchers and extension staff visited investigating many similar problems to those experienced within the Australian irrigation industry.

2. HAWAII

2.1 Visit 1 Hawaiian Agricultural Research Service, Aiea.

The Hawaiian Agricultural Research Service (HARS) is the new organisation formed from the remnants of the Hawaiian Sugar Planter's Association (HSPA) in an attempt to increase funding from non-sugar industry sources. This has been necessary due to the rapid decline of the Hawaiian sugar industry as a result of the reduction in the USA Federal Government import quotas for sugar. In the past, the USA import quota scheme has effectively been subsidising the local sugar industry. With the reduction in the quotas, much of the local industry has been uneconomic and is now closing down. There are now only five sugar plantations (down from 13 plantations two years ago) farming an area of approximately 80000 acres within Hawaii. The only sugar refinery in Hawaii was located on Oahu but closed down approximately a year ago with the land and buildings sold to a local T-shirt manufacturer. Raw sugar is currently sent to C&H Sugar in California for refining.

The HARS currently has a staff of approximately 50 (down from in excess of 200 two years ago) but is operating with an uncertain future. For the last two years, the HSPA has received a considerable amount of State government funding. However, as the State government currently has a deficit of approximately US\$300M the provision of these funds past June is in doubt.

Mr Lance Santo was my contact during the visit to the HARS. Mr Santo is an Agricultural Engineer who has been employed by the HSPA since the early 1970's. He undertook a

Master of Agricultural Engineering in drip irrigation design practices and Master of Agricultural Science in soil water movement under drip irrigation systems in the mid 1970's at the University of Hawaii and has been involved with the majority of the drip irrigation and agronomic research conducted by the HSPA since that time. He is the only irrigation agronomist on the HARS staff but is not currently involved in any irrigation research as the majority of his time is taken up conducting chemical registration trials for coffee and bananas. However, Mr Santo is also still involved in some irrigation extension activities for the sugar industry.

The majority of the HSPA drip irrigation research was conducted during the 1970's and early 1980's and reported in HSPA internal Irrigation Reports or the Proceedings of the Hawaiian Sugar Technologist conferences conducted during that time. Very little of this research appears to have been reported in refereed journals or sources. The following is a summary of the views expressed by Mr Santo on some of the topics discussed during the visit regarding drip irrigation practices:

- 'Pineapple' planting of sugarcane using 3ft row and 6ft bed spacings is almost exclusively used with drip irrigation in Hawaii to reduce the amount of tape required and hence, the cost of the drip irrigation installations. For the majority of soils, lateral wetting from the emitters has been shown to extend completely across the interbed spacings. There is no evidence to suggest that the rooting distributions or yields obtained under these conditions are any different from those obtained by other irrigation methods. In some cases, the tape is laid on the surface mid-distance between the rows. This has the advantage in many rocky areas of not having to be laid below the surface and appears to produce greater lateral wetting than subsurface drip systems under these conditions. However, it has the disadvantage of being susceptible to ant and rat damage. A significant amount of work conducted by the HSPA has identified damage resistant plastics and tape designs to minimise damage. The HARS still maintains live ant colonies to test the resistance of tape to ant damage.
- On selected soils, some problems are experienced with the germination of setts using subsurface drip irrigation due to inadequate lateral and vertical soil-water movement. In these cases, the initial irrigation is generally conducted using a temporary surface tube laid immediately above the row line.
- Irrigations are generally scheduled at twice weekly intervals with the amount of water applied determined from evapotranspiration demand calculated using local weather station data and the Penman equation.
- Where water supplies are limiting, crops are irrigated at 75% of the pan evaporation. Greater yields were obtained when the water was applied as a small amount each day rather than when the same total amount was applied in larger doses less frequently. There was no difference in the final yields when the limited water was applied to the first year or second year of the crop. This suggests that the effect of water stress on the final yield is the same irrespective of its timing during the growing period.
- There have been significant problems with the introduction of drip systems to Vertisols. These problems are generally related to the soil structural properties and tillage practices which produce large clod sizes and air voids. These structural properties influence the wetting patterns with large voids inhibiting the lateral

movement of water. There also appears to be problems with very slow soil-water movement away from the emitters in these soils inducing zones of saturation and salinisation. Production benefits associated with drip irrigation of sugar cane on these soils also appear to be the smallest of all soil types presumably due to the greater water holding capacity of these soils and hence higher yields under surface systems.

- The majority of the fertilisers and salts applied through the drip system appear to accumulate at the wetting front boundary. Fertiliser is applied at increasing amounts throughout the growing season starting at about 20lb/acre in the first month and peaking at about 80lb/acre/month during maximum growth periods. Fertilisers are applied at these varying amounts to match crop needs and to minimise losses to the groundwater. However, applications for the month tend to be applied during a single irrigation event. Slow injection of fertilisers have been shown to produce higher uniformities than fast injection methods.

2.2 Visit 2 Department of Agronomy and Soil Science, University of Hawaii, Manoa.

Prof Richard Green is the Professor of Soil Physics with the Department of Agronomy and Soil Science at the University of Hawaii. He has been with the university since the mid-1960's, has published over 110 scientific journal articles and book chapters, and supervised numerous students investigating soil-water movement and solute movement under both irrigation and non-irrigated conditions. Of particular interest was the research into modelling soil-water and chemical movement which Dr Green has been undertaking since the mid 1970's. Recently, he has also been involved in the measurement and modelling of pesticide transformations and movement within soils.

Prof Green suggested that there should be no need for any current research in this area to develop a model from scratch due to the ready availability of a number of packages that should be able to serve as building blocks for subsequent application programs. He provided details of the one-dimensional model developed by M.A. Khan and himself for soil water and nitrogen movement (Khan *et al.* 1981). During this discussion he also indicated that this particular model used several simplifying assumptions to improve computational speed. However, with recent advances in computers these assumptions were no longer necessary (nor desirable) and that a more appropriate one-dimensional model would be the "LEACHM" model developed by John Hutson and Jeff Wagenet at Cornell University, New York. This particular model has been undergoing continuing revision over several years and has the ability to simulate the movement of a variety of nutrients under a wide range of soil conditions. For two dimensional studies, he suggested investigating the "CHAIN_2D" model produced by J. Simunek and M. Van Genuchten at the U.S. Salinity Laboratory, Riverside.

During the visit with Prof Green, I inspected the Department of Agronomy and Soil Science research facilities and reviewed an experiment to measure the air filled void space and permeability of an intact soil core (Diameter = 250mm, Depth = 100mm) by using a differential pressure chamber and measuring the flow volumes transmitted.

2.3 Visit 3 Agsystems Inc, Maui

Mr Bill Pyle is an agricultural/civil engineer who has worked on Maui for 27 years. For the first 20 years, he worked for Hawaiian Commercial and Sugar as their drip irrigation designer, irrigation manager and workshop manager. For the last 7 years, he has been a private irrigation/water consultant undertaking design, installation and management contracts for drip irrigation of sugarcane, pineapples, grazing pastures, macadamias and coffee. He is also the local distributor for T-Tape. I spent almost a full day with Mr Pyle visiting a number of farms with a variety of crops and discussing local management practices. The following is a summary of the visits and discussions:

Average annual rainfall for much of the sugar producing area is less than 1000 mm with approximately 90% falling in winter from November to March. The drip irrigation systems in Maui are all fed from surface rainfall water collected by either collection channels or diverted from upland streams. Water storage is limited due by physical and economic constraints to about 10 days supply for cane land (about 20 days supply for pineapples). Water quality is good with low salt levels. Where water is sourced from steep sided valleys with few wild pigs and goats, biological levels are also low. Nearly all cane land is irrigated using gravity feed pressure. However, in some areas above the channels, other crops are grown. For small areas where the head is not sufficient to pressure the drip lines, a large volume of water is fed to a lower elevation through a supply line and used to power a turbine. This turbine is directly coupled to a smaller turbine which is able to pump a small proportion of the supply volume (but at higher pressure) back up the field for irrigation purposes.

Two different layouts are used to irrigate sugarcane on Maui. On high infiltration soils where lateral wetting is a problem, the tape is laid directly on top of the cane setts. On 'normal' soils, the tape is laid between the cane setts. In both cases, 'pineapple' planting is practiced. Most drill lengths are short (<200m) and there are no laser levelled fields. Extensive use of pressure restrictors are used to limit pressure in the laterals with changes in elevation.

Irrigations are normally conducted to wet the soil up to field capacity. In general, the recommendation is that the irrigation should be started when the soil has reached 50% of the available water capacity and water should be applied to bring the soil up to only 80% of the total available water capacity. This is to enable the crop to take advantage of any later rainfall that might occur. In practice, the irrigation scheduling and volumes applied are often dictated by operational difficulties such as the availability of water, the timing of weekends and the start/end time of the worker's shift.

2.4 Visit 4 Maui Pineapples, Maui.

During the visit to Maui, I was able to spend several hours with Mr John Wynn who is the Senior Agronomist with Maui Pineapples. Maui Pineapples is a large user of drip irrigation tape with approximately 10000 acres of pineapples under drip irrigation. However, although all the pineapples have tape installed, it is only very rarely (approximately once every five years) that the tape is used to supply irrigation water during the main part of the growing season. In most cases, the drip tape is only used to apply Nematicur during this time. However, having the ability to irrigate does provide a guaranteed yield and consistency of supply to the pineapple cannery.

Pineapples are grown at elevations from 60-720 m using a bedded row culture. The spacing of the pineapples along the rows is approximately 27 cm with row spacings within the bed of

approximately 60 cm. The drip tape is laid between the rows at a depth of 5 cm. One millimetre thick plastic mulch is used for weed control, moisture conservation and to increase the temperature of the soil. All fertiliser is applied using foliar sprays. An ethylene product is used to initiate flowering (applied as a liquid spray which vaporises to form ethylene gas). A small dose of the ethylene is also used 2-3 days before harvesting as a ripener to increase the sugar content. Crops are grown for about 18 months and may be ratooned if nematode levels in the soil are low.

2.5 Visit 5 Department of Agricultural Engineering, University of Hawaii, Manoa.

I spent a couple of hours with Dr I-Pau Wu who is the Professor of Irrigation within the Department of Agricultural Engineering at the University of Hawaii. Most of Dr Wu's research over the past 20 years has concentrated on the design limitations and practices of drip irrigation systems. He is currently only a couple of years away from retirement and has only one postgraduate student. During this visit we discussed Prof Wu's current research investigating the variations in application efficiency associated with three dimensional flow from point source emitters. The preliminary results of this work suggest that there is a significant difference in the distribution uniformity and application efficiency of drip irrigation depending on the dimension studied. This work has important implications for root uptake patterns and the validity of the current techniques used to evaluate alternative designs and management practices for drip irrigation systems.

3. UTAH

3.1 Visit 6 Department of Biological and Irrigation Engineering, Utah State University, Logan.

Utah has 730 000 ha of irrigation land (almost exclusively surface irrigated) of which about 37% is used for pasture/hay production and a further 29% used to grow alfalfa. This reflects the dairy industry's demand for feed in the state. Other significant crops include grain, corn and fruit trees. Utah State University (USU) is the state land grant university and as such has a significant emphasis on both research and extension activities to the rural sector.

The Department of Biological and Irrigation Engineering at USU teaches both undergraduate and postgraduate courses in bioprocessing, food engineering, agricultural waste management, soil management and irrigation systems. The Department's staff (of about 20) has worked on projects at both state and national levels and has worked on irrigation research and training projects in more than 70 countries. Current research projects within the department in bioprocessing include ventilation and environmental control of livestock buildings, the contribution of rural municipalities to non-point source pollution, and agricultural waste management systems. Land application of food processing wastes, extrusion of dairy based foods, multi-stage anaerobic digestion of biological materials, functional properties of foods, and biological detoxification of metals are some of the topics being pursued in food engineering. I spent most of my time with the soil and water resources group whose current research activities are focused on improving irrigation system and project management through remote sensing, electronic data transfer and manipulation, computerised management and decision-making for irrigation schemes, and planning and management for sustainable

agricultural production systems. Some drainage research is also being conducted on synthetic drain envelope materials and factors that cause drain clogging while salt balance research as it relates to both drainage and water management is being done in both the laboratory and the field. Other projects being undertaken include the optimisation of regional and local scale groundwater utilisation, groundwater quality management, and coordination of the use of groundwater and surface-water resources. The systems simulation/optimisation laboratory develops and applies computer models addressing a wide range of flow, transport, and equilibria problems. The Department is also directly involved in overseas research and training activities concerned with on-farm water management, water resource development, and irrigation project management through the International Irrigation Center.

Prof Wynn Walker is the Professor of Irrigation and Drainage and Head of the Department of Biological and Irrigation Engineering at USU. He has authored many journal articles on surface irrigation design, management and modelling, is the senior author of one of the major texts on surface irrigation and has written a range of computer programs for irrigation research and training. During my time with Prof Walker we discussed a wide range of topics relating to irrigation and drainage. Of particular importance was further development of his surface irrigation modelling program SIRMOD which has been used within BS90S. Prof Walker has already made a number of changes to this program in response to issues and concerns raised by the *BS90S* project work. These modifications were discussed along with a range of other potential changes that would enhance the appeal of the program within the Australian sugar industry. While there is little current interest (and research funding) in surface irrigation within Utah, Prof Walker is currently working on a new Windows version of this program which should be completed by the end of 1996. However, this version is not intended to have a design or management optimisation capability. As this is an area that has been identified as necessary for the model to be broadly adopted in an extension capacity, Dr Walker suggested that he could supply a “cut-down” version (excluding input and graphic screens) that could be used as an “engine” in a customised iterative process for design evaluation and optimisation. This opportunity is currently under investigation within the University of Southern Queensland.

Prof Richard Allen is a member of faculty within the Department of Biological and Irrigation Engineering and has conducted a large amount of research investigating the theoretical principles governing the physics and physiology of evapotranspiration and developing practical equations for ready and consistent application. He is currently on the FAO working committee identifying appropriate irrigation scheduling technologies for both developed and developing countries. Much of this work has concentrated on the development of simple irrigation calendars which have been developed for specific crops in specific locations based on planting date and expected rainfall/evaporation demands. This work may be of interest to the Australian irrigation sector as a first step in providing advice for irrigation scheduling. It is a simple, low cost technique which provides a simple level of direction to farmers who are currently not scheduling irrigations. This approach is particularly useful in areas with either low rainfall or a high degree of predicability in rainfall patterns. Prof Allen also expressed interest in the mini-pan evaporation work conducted by BSES and has passed on a copy of the paper prepared for the Irrigation Association of Australia conference on this work to representatives of the FAO for inclusion in their review program.

Dr Gary Merkley is an Associate Professor within the Department concerned primarily with the development of computer monitoring and control packages for irrigation management. He is principally a hydraulics and computer specialist and has co-authored several of the

department's irrigation management computer packages. Dr Merkley provided me with a number of recently released irrigation management and modelling packages which may be useful within the Australian irrigation industry.

Dr Robert Hill is the Irrigation Extension Specialist within the Department. He is principally involved in applied research activities which are conducted either on commercial farms or the University's research farm. Much of his current work has been directed towards the implementation of surge techniques for surface irrigation. Interestingly, USU was one of the pioneers of surge irrigation and holds the first patent on a surge controller. However, recent results suggest that for the small fields found locally (typically 200m x 200m) in Cache Valley, large flow basin irrigation is more efficient than the traditional furrow irrigation methods. This appears to be related to the potential for shorter opportunity times for infiltration under this system.

3.2 Visit 7 International Irrigation Center, Department of Biological and Irrigation Engineering, Utah State University, Logan.

The International Irrigation Center (IIC) was established in 1980 as part of the Department of Biological and Irrigation Engineering at USU in response to an increasing need to enhance the training and research capabilities of professionals and scientists outside of the USA for improving irrigated agriculture in their countries. I spend a short time at the centre discussing its operation with the director Dr Humberto Yap Salinas. The general objectives of the IIC are:

- To provide a training in agricultural water management and utilisation geared to the responsibilities and functions of personnel managing water for societal development.
- To promote applied research that is basic to the needs and constraints of developing societies.
- To maintain a technical resource entity specialising in the processes of utilising water for agricultural production and societal development.
- To contribute to international cooperation and understanding through professional activities of the technical staff, effective research and special studies and enhanced capability of the trainees.

The staff in the IIC are generally drawn from Utah State University staff in the Departments of Biological and Irrigation Engineering; Sociology; Plant, Soils, and Biometeorology; Economics; Agricultural Systems Technology and Education; Geography; and Civil and Environmental Engineering. Experts are sometimes brought in from outside the University to teach specialised subjects when their particular field of expertise is not available on campus.

The training activities of the IIC include a number of regularly scheduled courses related to the management of irrigated agriculture. These courses have been designed not only to cover a wide range of subject matter, but also to provide training for a range of technical expertise from high-level planners and directors to those field technicians who are primarily responsible for the field work. The Centre also develops technical training courses at the request of different countries in order to reach a larger number of professionals. Several

countries (mainly South American) have organised courses in conjunction with the IIC under the sponsorship of different donor agencies. The IIC also offers a number of possibilities to pursue non-degree programs in which a student is able to carry out specialised studies in particular subject areas ranging from three to 15 month's duration.

Dr Yap Salinas suggested that the current emphasis of government and other funding bodies around the world involves the transfer of operation, maintenance, and management of irrigation delivery systems from government entities to independent water user organisations for more efficient operation and improved crop production. This involves the formation of functioning water user organisations to facilitate the transfer of control. The Centre is currently attempting to target its training programs at the growers who will comprise these water user organisations to develop the expertise to manage their irrigation systems effectively. This is similar to the situation currently being faced in Queensland with the expected transfer of water delivery infrastructure from government control to local water user control. It also raises the question of whether there is a need to conduct short training courses to provide these water users with the technical knowledge required to effectively manage these systems.

3.3 Visit 8 Department of Plants, Soils and Biometeorology, Utah State University, Logan.

Dr Dani Or is Associate Professor of Soil Physics within the Department of Plants, Soils and Biometeorology (PSB) at USU. He is conducting a wide range of irrigation and water movement research projects which have direct application in drip irrigation management. This research includes (i) using time domain reflectometry (TDR) to control and monitor flow and transport from point sources, (ii) identifying the dielectric spectroscopy of soil constituents across a broad frequency range (DC to 18 Ghz), (iii) evaluating unsaturated soil hydraulic properties using subsurface point sources, (iv) investigating the limitations to using saline waste water from electrical power plants for irrigation and (v) investigating the effects of variability in soil properties on transient flow from point sources in heterogeneous soils. He is also developing a customised Windows-based program to control a Tektronix 1502B TDR Cable Tester (and multiplexer) for waveform analysis of water content and EC in soils and is exploring the effect of growth media on the gaseous and liquid fluxes to plant roots under microgravity.

4. CALIFORNIA

4.1 Visit 9 **United States Department of Agriculture - Agricultural Research Service, Water Management Research Laboratory, Fresno.**

The Water Management Research Laboratory (WMRL) is operated by the USDA-ARS and conducts irrigation and drainage research within the San Joachim Valley. It has a staff of approximately twenty led by Dr Tom Trout who is an Agricultural Engineer with extensive experience in surface irrigation design and management. The Laboratory was previously led by Dr Parlange who conducted a significant amount of the drip irrigation design and management research during the 1980's. Staff from the WMRL have published over 400 research articles on various irrigation and drainage practices over the past 17 years. I spent a day visiting the WMRL during which I spoke with several staff and was shown through the laboratory itself and two of the field research sites operated by the WMRL in the San Joachim Valley.

Dr Jim Ayers is an irrigation and drainage specialist at the WMRL. He has conducted extensive work on evapotranspiration and water requirements for a range of tree and horticultural crops but his major current focus is associated with the use of shallow groundwater tables for supplying the crop water use requirement during the growing season. In many parts of the San Joachim Valley, the water table is about 1-2 m below the soil surface (with electrical conductivities ranging up to 15 dSm^{-1}). The groundwater tables are not able to be drained due to environmental controls on the discharge and movement of selenium and boron in the waters. Thus there is an urgent need to manage irrigation water use and to control the water table and water movement by selective drainage and crop use. There is currently no way to dispose of the salt building up within the system. While it is possible to drain the areas and evaporate the water off to stockpile the salt, they are unable to legally dispose of the salt in any way at this stage.

Dr Ayers has been conducting lysimeter trials in the San Joachim Valley over the past 15 years. He has recently received funding to install two large lysimeters at one of the field stations. These lysimeters will be initially used to determine the effect of a perched water table at various depths on the evapotranspiration and growth of a variety of crops. One possible management strategy is that the first few irrigations in the season will be used to establish the crop root system and may assist to flush salts accumulated in the soil during the previous season down to the water table, as well as raise the water table to a moderate depth where the established roots can access the water. Subsequent irrigations will be applied as necessary to manage the water table depth and crop needs.

Other work of interest currently being conducted at the WMRL includes that of:

- a PhD student (being jointly supervised by Dr Ayers) investigating two dimensional water distribution patterns from point source emitters. He has collected distribution data using destructive gravimetric sampling for a range of soils and drip systems with the intention of producing a series of two dimensional empirical wetting pattern functions.

- a visiting soil scientist investigating the nitrogen dynamics of cotton under drip irrigation. This is a five year study that is only in its third year. Early results are available within the WMRL annual reports.

Mr Richard Mead is a Soil Scientist at the WMRL, Fresno. He has been involved in most of the drip irrigation research conducted in the San Joachim Valley over the past 12 years and is the manager of the World Wide Web Discussion Group on drip irrigation called TRICKLE-L. This Discussion Group has been operating for two years and currently has over 400 participants from around the world contributing regularly. Participation is open to anybody with an interest in drip irrigation and currently includes farmers, extension officers, consultants, tape suppliers, manufacturers and researchers.

4.2 Visit 10 Center for Irrigation Technology, California State University, Fresno.

The Center for Irrigation Technology (CIT) is a self-funding centre operated by California State University, Fresno (CSUF). It has a primary focus on testing and certifying irrigation equipment for manufacturers but also obtains a considerable proportion of its operating funds from field research projects and market analytical studies. It also conducts user-pays training and extension courses for farmers and irrigation industry personnel and is the administrative centre for the examination and certification of irrigation designers under the Irrigation Association (USA) accreditation program. This Centre is also performing the same role for the Irrigation Association of Australia (IAA) and is currently in the process of revising the USA Irrigation Association course and examination requirements to suit Australian requirements.

4.3 Visit 11 Irrigation Training and Research Center, California Polytechnic State University, San Luis Obispo.

The Irrigation Training and Research Center (ITRC) is part of the Department of Agricultural Engineering at Calpoly. It is recognised for its work in the areas of landscape and agricultural irrigation efficiency and water conservation as well as canal automation. It specialises in diagnostic irrigation and drainage research and expert system development as well as the training of industry personnel in both on-farm and off-farm irrigation and drainage system management. The research and teaching facilities at the centre include an irrigation practices field with a wide range of irrigation systems (spray, drip and surface) and a pumping and water delivery facility worth >US\$1M which is used for canal design and management studies. All projects at the ITRC are self-funding with the majority of the equipment supplied by industry donations. Training programs have been conducted for a wide range of both private and government organisations from both within and outside the USA. The Centre will conduct a training program for 20 Australian irrigation specialist later this year as part of their preparation for certification as irrigation designers by the Irrigation Association of Australia. It would seem appropriate that the University of Southern Queensland, through the National Centre for Engineering in Agriculture, investigate the potential to conduct similar preparatory courses on a fee for service basis in the future. Other specialist courses conducted by the ITRC include: canal automation, row crop drip irrigation, microspray design, agricultural irrigation evaluations, fertigation, surface irrigation, landscape irrigation auditor training,

flow measurement design and concepts, and supervisory control, remote monitoring and control.

While at the Centre, I spent some time with Dr John Merriam who is Emeritus Professor of Irrigation within the Department of Agricultural Engineering. Dr Merriam has conducted an extensive amount of surface irrigation research over the last forty years and is currently involved in the development of flexible delivery systems for surface irrigation which reduce installation costs and enable growers to use water on-demand. This work is primarily targeted towards developing countries with implementation currently occurring in Pakistan and Sri Lanka but has been successfully used on small scales within the USA. It involves the development of localised (or even on-farm) water storage structures that can be filled during low demand flow periods (often at night in the areas studied) from the main supply channel. Farms along the supply channel above the storage structure use water on demand (generally during the day) and excess water is used to supply the water storage. Farms below the storage structure draw water on-demand from channels which are supplied from the local storage capacity. The main benefit of this system is the reduction in the size of the supply channels required for the irrigation area while still providing the flexibility of an on-demand supply system.

4.4 Visit 12 Department of Land, Air and Water Resources, University of California, Davis.

Dr Blaine Hanson is the Irrigation and Drainage Extension Specialist within the Department of Land, Air and Water Resources at UC-Davis. He is the senior irrigation extension officer for much of California and has worked extensively on spray, surface and drip irrigation systems. Although primarily involved in extension orientated activities, he has conducted a considerable research program in the field orientated and applied components of furrow and drip irrigation. He is also the author of several farm management and irrigation advisory books on salinity, irrigation and drainage and is currently working on several irrigation research projects with a similar focus to those being either undertaken or proposed by the Australian sugar industry. In particular, his work on furrow irrigation performance on cracking clay soils has found substantial lateral movement of water (up to 6.5 m) through subsurface cracks and differences in infiltration due to wheel tracks and pre-irrigation soil moisture. There was also no significant irrigation efficiency benefit in reducing furrow length below 720 m on these soils. All of these results confirm those obtained in the trials conducted within *BS90S*. However, significant differences in irrigation infiltration and efficiency on cracking clay soils were also found with changes in water application rates. This is at a variance to the *BS90S* results which showed no difference between water application rates on cracking clay soils. Dr Hanson explains the difference as a function of the greater depth of flow increasing the direct water access to the crack volume within the beds. This may explain the differences between the studies as the bed (hill) width used in the sugar industry is much smaller than that used by many of the row crops studied by Dr Hanson and could thus be expected to have a proportionally smaller effect on the total infiltrated volume.

Several specific problems associated with drip irrigation of row crops were also discussed during the visit. In contrast to the recommendations of the USDA-ARS at Fresno, Dr Hanson recommends that drip irrigated crops should be irrigated only once per day (as opposed to 2-3 times per day) but may be irrigated at frequencies of up to twice a week without appreciable yield losses. Soils are irrigated to field capacity usually using the slowest feasible water

application rate. He has found that especially on cracking clay soils, the rate of water movement through the soil is often so low that the wetting front does not extend very far from the emitter. In some cases (e.g. drip irrigation of tomatoes), the wetted zone will contract towards the emitter throughout the season as the crop extracts water from the bulk soil volume faster than it can be replenished from the point source. In this case, the roots often form a ball around the wetted zone which tends to approach saturation. Hence, the roots are exploring a smaller soil volume and are susceptible to root rot diseases. The solution in these cases has been to reduce emitter spacings and apply the water at a very low rate to increase the opportunity time for soil-water movement.

The volume of water to be applied in drip irrigations is normally calculated from weather data obtained from CIMMIS stations located locally (in excess of 100 throughout the state). This weather data can be obtained by the grower by dialling directly into the local station and downloading the data using a customised interface. The irrigation practice is typically also monitored using a low cost soil-water monitoring device such as tensiometer or gypsum block. In this case, the monitor is normally placed 15-20 cm from the tape at a depth midway within the rooting depth of the crop (usually 15-20 cm). If the monitoring device indicates a drying trend throughout the season, then the grower knows to apply more, whereas if the soil remains moist it indicates that excessive water is probably being applied. The main problem with using the calculated evapotranspiration (E_t) for determining the irrigated volumes to be applied by drip systems is that the crop factors have usually been calculated using a surface irrigated crop. Under these conditions, Dr Hanson believes that the surface irrigated crop would be expected to have a high evaporative loss and higher total evapotranspiration losses than a drip irrigated crop. Hence, using calculated E_t could be expected to overestimate the irrigation water required to be applied (especially early in the season). To identify the presence and/or magnitude of these errors, Dr Hanson is currently collecting data for crop factors obtained under drip irrigation in Fresno.

Prof Wes Wallender is Professor of Water Resources within the Department of Land, Air and Water Resources. His main areas of expertise have been in surface irrigation, overland flow and infiltration functions. He has recently changed his focus from studies of irrigation practices at a fundamental level to catchment wide evaluations. He is currently actively involved in the use of geographic information systems to provide spatially variable inputs for hydrologic modelling under both irrigated and rainfed conditions. This work has been undertaken in the Panoche County irrigation area and investigates the effect of precipitation, crop, soil, topography and irrigation management practices on ground water fluctuations, pesticide and chemical movements and surface water flows. In particular, the system can be used to highlight problem areas or practices where the watertable is rising or areas where excessive levels of pollutants might be expected. The aim of this work is to build a simulation package that can be operated using virtual reality processes. Prof Wallender suggested that this package would ideally be used to demonstrate to growers, industry representatives and policy makers, the effects of various management and political decisions on a range of environmental and production variables such as soil erosion, fluctuations in watertables, and riverine stream flows, and crop yields. This package will also enable resource users to “see” the effects of various management scenarios before they implemented specific management practices.

5. ACKNOWLEDGMENTS

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Appendix 1 **TRAVEL ITINERARY**

- Day 1 Travel Toowoomba - Sydney
- Day 2 Travel Sydney - Honolulu
- Day 3 Rest day
- Day 4 Visited Mr Lance Santo (Hawaiian Agriculture Research Service, Aiea)
Visited Professor Richard Green (Agronomy and Soils, University of Hawaii,
Manoa)
- Day 5 Rest day
- Day 6 Visited Mr Bill Pyle (Agsystems Inc, Maui)
Visited Mr John Wynn (Maui Pineapples)
- Day 7 Visited Professor Ipau Wu (Agricultural Engineering, University of Hawaii,
Manoa)
- Day 8 Rest day
- Day 9 Travel Honolulu - Salt Lake City
- Day 10 Rest day
- Day 11 Travel Salt Lake City to Logan
- Day 12 Visited Professor Wynn Walker and other staff in Biological and Irrigation
Engineering at Utah State University
- Day 13 Visited Professor Wynn Walker and other staff in Biological and Irrigation
Engineering at Utah State University
Visited Dr Dani Or (Department of Plants, Soils and Biometeorology,
Utah State University)
- Day 14 Travel Logan - Salt Lake City
Travel Salt Lake City - San Francisco
- Day 15 Rest day
- Day 16 Rest day
- Day 17 Travel San Francisco - Fresno
- Day 18 Visited Dr James Ayers and Mr Richard Mead (USDA-ARS, Water
Management Research Laboratory, Fresno)

- Day 19 Visited Mr David Zoldoske and Ms Kate Norum (Center for Irrigation Technology, California State University, Fresno)
Travel Fresno - San Luis Obispo
- Day 20 Visited Professor Charles Burt, Professor Emeritus John Merriam and Mr Stuart Styles (Irrigation Training Research Centre, California Polytechnic State University, San Luis Obispo)
- Day 21 Travel San Luis Obispo - San Francisco
- Day 22 Travel San Francisco - Davis (return)
Visit Professor Wes Wallender and Dr Blaine Hanson (Department of Land, Air and Water Resources, University of California, Davis)
- Day 23/24 Travel San Francisco - Toowoomba

Appendix 2

LIST OF PUBLICATIONS OBTAINED DURING VISITS

Copies of the following software programs and publications were obtained during the visits. Interested readers may obtain copies of these documents by either contacting the relevant authors directly or by contacting myself.

Software

STEADY Version 2.4 (April 1994) A steady state canal hydraulic model. Biological and Irrigation Engineering, Utah State University, Logan.

PDM - PLANNING AND DISTRIBUTION MODEL (April 1996) A spatial distribution model used for monitoring and planning development of water distribution systems on a state, regional or catchment scale. Biological and Irrigation Engineering, Utah State University, Logan.

CANALMAN Version 5.4 (January 1996) Hydraulic simulation model for canal design and management. Biological and Irrigation Engineering, Utah State University, Logan.

2D BASIN IRRIGATION SIMULATION MODEL Version 1.0 (1992) Biological and Irrigation Engineering, Utah State University, Logan.

Manuals/Books

Annual Progress Report (1994) USDA-ARS Water Management Research Laboratory, Fresno.

Azevedo, C.A.V. (1992). Real-time solution of the inverse furrow advance problem. PhD Thesis, Utah State University, Logan. (extracts only)

Hanson, B., Schwankl, L., Grattan, S.R. and T. Prichard (1994) *Drip irrigation for row crops*. University of California Irrigation Program, Davis. Water Management Series Publication 93-05.

Listing of Scientific Publications of the Water Management Research Laboratory (1996) USDA-ARS Water Management Research Laboratory, Fresno.

Playan, E., Merkley, G.P. and W.R Walker (1992) *Two-Dimensional Basin Irrigation Simulation Model, Users Guide*. Dept. Biological and Irrigation Engineering, Utah State University, Logan.

Proceedings of the Subsurface Drip Irrigation: Theory, Practices and Applications Meeting. 22 October, 1992, Coalinga, California. California Agricultural Technology Institute, Publication 921001.

Skogerboe, G.V., Ren, L., and D. Yang (1993) *Cutthroat Flume Discharge Ratings, Size Selection and Installation*. International Irrigation Center, Utah State University, Logan.

Skogerboe, G.V., Walker, W.R., Evans, R.G., and J.P. Law (1986) *Planning Manual for Salinity Management in Irrigated Agriculture*. International Irrigation Center, Utah State University, Logan.

Journal Articles

Allen, R.G., Smith, M., Perrier, A. and L.S. Pereira (1994) An update for the definition of reference evapotranspiration. *ICID Bulletin* 43(2):1-92.

Chen, C., Green, R.E., Thomas, D.M. and J.A. Knuteson (1995) Modeling 1,3-Dichloropropene fumigant volatilization with vapor-phase advection in the soil profile. *Environmental Science and Technology* 29: 1816-1821.

Coelho, F.E. and D. Or (1996) A parametric model for two-dimensional water uptake intensity by corn roots under drip irrigation. *Soil Science Society of America, J.* (in press)

Coelho, F.E. and D. Or (199_) Applicability of analytical solutions for flow from point sources to drip irrigation management. (submitted to *Soil Science Society of America, J*)

Hanson, B.R., Fulton, A.E. and D.A. Goldhamer (199_) Furrow irrigation performance under a cracking soil. (in prep.)

Hill, R.W. and J. Keller (1980) Irrigation system selection for maximum crop profit. *Transactions of the ASAE*: 366-372.

Jackson, R.D., Jones, C.A. Uehara, G., and L.T. Santo (1980) Remote detection of nutrient and water deficiencies in sugarcane under variable cloudiness. *Remote Sensing of Environment* 11: 327-331.

Kemper, W.D., Bonduant, J.A. and T.J. Trout (1986) Irrigation trash screens pay! *Journal of Soil and Water Conservation* 41.

Khan, M.A., Green, R.E. and P. Cheng (1981) A numerical simulation model to describe nitrogen movement in the soil with intermittent irrigation. *Hawaii Institute of Tropical Agriculture and Human Resources Research Series* 010. University of Hawaii, Manoa.

Khan, M.A., Green R.E. and T. Liang (1986) Nitrogen transformations in soils: experimental and mathematical considerations for computer modeling. *Hawaii Institute of Tropical Agriculture and Human Resources Research Series* 045. University of Hawaii, Manoa.

Lee, C.C., Green, R.E. and W.J. Apt (1986) Transformation and adsorption of fenamiphos, f.sulfoxide and f.sulfone in Molokai soil and simulated movement with irrigation. In D.L. Macalady (ed), Transport and Transformations of Organic Contaminants. *J. Contaminated Hydrology* 1: 211-225.

Or, D. (199_) Wetting induced soil structural changes: the theory of liquid phase sintering. *Water Resources Research* (submitted).

Or, D. and F.E. Coelho (1996) Soil water dynamics under drip irrigation: transient flow and uptake models. *Trans. ASAE* (in press).

Or, D. and H.R. Silva (199_) Prediction of surface irrigation advance using soil intake properties. (in prep)

Santo, L.T. and G.Y. Tsuji (1977) Soil bulk density and water content measurement by gamma-ray attenuation techniques. *Hawaii Agricultural Experiment Station, Technical Bulletin 98*. University of Hawaii, Manoa.

Standley, C.D., Green, R.E., Khan, M.A. and L.T. Santo (1990) Nitrogen-fertilization rate and soil nitrate distribution for microirrigation of sugarcane. *Soil Science Society of America Journal* 54: 217-222.

