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M-A-03: Socioeconomic value of irrigation

Rumzi Ahmad - Uplifting the socio economics of farmers in Muda area: the role of irrigation systems - INTRODUCTION Rice is a strategic commodity for Malaysia as it is the staple food of its population. Given the fact that Malaysia population are the main consumers who spend a large portion of their income in purchasing rice for domestic consumption, the growth and stability of this commodity is of paramount importance. Having said that, since 1955 until several years after independence, the Malaysian Government had taken measures to ensure rice sufficiency in the country. In light of this, the Government spearheaded a number of agricultural projects under the First Malaysia Plan (1966-1970). It is worth noting that Muda Irrigation Scheme is the main highlight of this plan, which has been brought to fore by the Federal Department. Following this, the Malaysian Government had embarked on the construction work in April 1966. The first stage of the irrigation, which kick started in the early 1970, covered approximately 30,565 hectares of off-season crops. The project encompasses four phases which had come to a full completion in 1976. In line with this success, the Government has advanced its policy to the next level, in which instead of aiming for sufficient supply of rice, the Government aspired to elevate the welfare and social status of the communities in agriculture industry. To fulfill this aspiration, there is a dire need for the Government to focus the irrigation system in Malaysia, particularly in Muda area, as it is one of the major water regulation technologies that is the key in improving the agriculture standard in the country. The aim of this paper is to discuss the functions of irrigation systems in Muda area, especially in terms of uplifting the socioeconomic status of farmers in the said area. THE ROLE AND FUNCTIONS OF IRRIGATION SYSTEMS IN MUDA AREA In 1966, the Muda Irrigation Scheme was implemented in 96,000 hectare Muda area, a coastal plain which straddle the two states of Kedah and Perlis in the north west of Peninsular Malaysia. This project received International Bank for Reconstruction and Development (IBRD) financing totaling US$45 million and was successful in introducing a second crop of rice in the project area. As a result, cropping intensity increased sharply to 176%. Within a few years of project implementation however, the project staff was able to identify the shortcomings of the project. The main problem was that the infrastructure was inadequate to bring out full production potential in the area. Following this, a new project called the Muda II project was formulated and an IBRD loan of US$31 million was secured to finance the foreign exchange component of the project. The objectives of this project are to overcome the supply and drainage problems of high and low grounds within the project area as well as to bring about productivity and production increases through better water management. The project is envisaged to be the first phase of tertiary development in the Muda project area and it covers 38 irrigation blocks distributed over the entire Muda area or an equivalent of 27 percent of total area. It is aimed at intensifying the level of infrastructure by the construction of tertiary canals, drains, and farm roads to serve the 27,400 hectares covered by the project. A total of 16,000 farmers operated paddy farm within the project area. By the year 1987, the Muda II project completed which involved total cost RM 225 million. In terms of productivity of paddy, there is a significant increase of paddy production for the farmers and nation at large after the completion of Muda I and Muda II. Specifically, before the implementation of the Muda I and Muda II project, the average yield for farmers in the Muda area are 3.37 ton/ha while the yield after the implementation of the projects are 4.178 ton/ha. Furthermore, back in 1979, the Government of Malaysia had introduced paddy fertilizer subsidy scheme. This policy was aimed at reducing the cost of production for farmers producing paddy. The initial result showed a substantial increase of 4.674 ton/ha in terms of productivity. The incidence of poverty level among the farmers in Muda area was 72% of the population at that time, which were considered high. The increased yield after the implementation of the government projects has augmented the productivity and resulted in extra income for the farmers. This has inadvertently reduced the poverty level, in which the poverty statistics recorded almost half the percentage of reduction, following the increase of paddy productivity. Within the five decades of the implementation of Muda Project, the Government has introduced various packages to help farmers, including paddy fertilizer subsidy scheme, implementation of 10 tones project, paddy production incentive scheme, and national key economic area (NKEA) EPP 10. These strenuous efforts are deemed worthwhile as the yield of farmers productivity in Muda area consistently showed an increasing pattern. In order to increase and sustain the income of farmers in Muda area, the government had implemented the policy of Guaranteed Minimum Price (GMP) for paddy produced by farmers in Muda area. The policy started in 1949 and had been since revised eight times. Currently, the price of paddy in Muda area stood at RM 1200/ton. Among the indicators are the fact that currently, the income of the farmers in Muda area stood at RM 31,500 yearly while poverty level are at very minimal of 1.0% and 0.5% for poor and hard core poor, respectively. THE WAY FORWARD A deliberate shift in the Government's policy and effort over the past five decades has resulted in a strengthening of paddy production, in particular as well as rural development of the Muda area at large. Evidently, such efforts, which integrate productivity and antipoverty aspect as the main focuses, have benefited farmers of various scales. The strategies and programs implemented by the Government have elicited new types of projects that managed to address and overcome economic, sociological, institutional, and technological problems in relation to paddy productivity. The government has continuously assessed the effectiveness of various measures taken and the operational experience of rural development projects. This step is also crucial in designing monitoring and evaluation systems for such programs related to paddy production. Further, various programs have been developed to elevate the paddy productivity. Among others are the establishment of new paddy estate and water usage group, adoption of a fully centralized paddy estate management, harvesting based on tonnage yield, and the use of new technology of fertilizer usage. Having acknowledged the importance of diversifying knowledge and skills among farmers in boosting their living standards, the Government has designed two most relevant programs, namely guided agro-based entrepreneur and new young agro-based entrepreneur. Taken together, over a period of the last five decades, the agriculture activity in Muda area has experienced significant intensification. The process of agricultural intensification due to a range of factors is both a cause and an effect of the extraordinary efforts taken by the government. Most importantly, the livelihoods of a vast majority of the people in the region are critically dependent on the booming of the agricultural industry, particularly in paddy production. Nevertheless, the need to increase productivity is one of the many challenges faced by the Government and other authorized bodies in charge of Muda area. Despite these challenges, entrusted entities that are responsible for Muda area have to continuously strive to maximize paddy productivity, which is a prerequisite towards the achievement of income-poverty alleviation agenda for the nation."

M-B-03: Climate change and its impact on agriculture, irrigation, and drainage (I)

Mr. David Curtis - Perspectives on California’s Wet and Wild 2016-17 Winter Season - A Wet and Wild 2016-17 Winter Season and Recent Precipitation Trends on the US WEST Coast. Drought, severe drought, extreme drought, atmospheric rivers, more atmospheric rivers, floods, snow pack, full reservoirs, soggy soils, infrastructure damage, full allocations â€“ all words and phrases permeating recent California water conversations. If anything, these words, all used during the 2016-17 winter season, show how quickly California's precipitation regime staggers and lurches from dry to wet and back again. Mired in drought for half a decade, storm after storm brought much needed relief to all of California, especially agricultural interests who had experienced severe cutbacks. During the following summer, surrounded by lush landscapes, the transformation seemed truly remarkable as drought memories faded from short term memory. How quickly we forget. But, we shouldn't forget. If fact we should consider how this epic season fits in historical context and how 2016-17 might compare to what's in store for California. This presentation takes a look at precipitation in California where we are fortunate enough to have records dating back a century and half and snowpack observations for nearly a century. Some important trends are present that reflect significant vulnerabilities in water supply. We peer further back into our precipitation history with the help of 1100-years of tree ring to see the strength of natural precipitation variability that underlies impacts of more recent climate change. Then, we read some tea leaves to infer what we might expect from a future climate.

Mr. Phokele Maponya - Potential Constraint of Rainwater availability on the Establishment and Expansion of Agroforestry in Limpopo Province, South Africa - Agroforestry is a land use system that includes the use of woody perennial and agricultural crops and animals in combination to achieve beneficial ecological and economical interactions for food, fiber and livestock production. Properly managed Agroforestry system provides multiple benefits and contribute to improved livelihoods and income generation. Agroforestry systems are also area and climate specific hence it is key to develop agroforestry systems that are locally relevant, and consider the biophysical and socio-economic context on a case by case basis. South Africa is considered a semi â€“ arid country vulnerable to water stress, particularly drought. Limpopo province average annual rainfall is 600 mm and the threshold for rainfall agriculture is averaged at 250 mm annually. In terms of forestry, the plantation forests of South Africa use just 3% of the country's total water resources and rainfall needs to be higher than 750 mm per annum to sustain commercial forestry. The objective of the study was to determine the potential constraint of rainwater on the establishment and expansion of Agroforestry in Limpopo province. A purposive sampling technique was used to select 65 Agroforestry systems from the list provided by Department of Agriculture, Forestry and Fisheries and Forestry South Africa Limpopo. The Agroforestry systems were visited and identified as follows: Silvipasture (32); Agrosilvoculture (3); Agrosilvipasture (23); Apiculture (1) and Agrosilvipasture & Apiculture (6). Quantitative and qualitative designs were used as a questionnaire written in English, stakeholderâ€™s discussion and field observations were part of the data collection. Decadal (ten day period) 1km X1km surfaces were created from rainfall data downloaded from the AgroMet databank at the Agriculture Research Council â€“Institute of Soil, Climate and Water (South African Weather Service and ISCW weather stations) from stations with a period of 10 years or more. Regression analysis and spatial modelling were utilized taking into account topographic indices such as altitude, aspect, slope and distance to the sea during the development of the surface. The socio economic data was also coded, captured and analysed using Statistical Package for Social Science (SPSS). The September 2017 rainfall results indicated that there was generally low rainfall (0 â€“ 25mm) for most parts of the Limpopo Province. In some parts of Vhembe, Capricorn and Mopani districts there were some rainfall (20 â€“ 50mm and 51 â€“ 75mm). Most of the agroforestry systems visited fell under those areas in Limpopo province.The October 2017 rainfall situation improves in the whole province with more increase in rainfall (75 â€“ 100mm; 101 â€“ 125mm and 126 â€“ 145mm) in the study areas (Vhembe, Mopani and some of Capricorn). This situation is not surprising as Forestry South Africa and Department of Agriculture, Fisheries and Forestry had identified those districts as good for establishment and expansion of agroforestry. During 2017 November and December increasing rainfall was experienced in the study areas (Vhembe, Mopani and some parts of Capricorn). The study areas were experiencing 126 â€“ 150mm; 151 â€“ 175mm; 176 â€“ 200mm and 201 â€“ 220mm) respectively. This trends offers a good platform for the establishment and expansion of agroforestry as rainwater is not a constraint as compared to other districts in Limpopo province (Waterberg, Sekhukhune and some parts of Capricorn). The last three rainfall status (33rd, median and 66th percentile annual rainfalls) indicated the estimates of rainfall in the future years. It estimated annual rainfalls at 601 â€“ 700mm to 1001 â€“ 2216mm across 33rd, 50th and 66th percentiles. This rainfall situation is well above the Limpopo province annual average rainfall (600mm). It can thus be concluded that rainwater is a constraints in some districts in Limpopo province (Waterberg, Sekhukhune and some parts of Capricorn district) for the establishment and expansion of agroforestry and in Vhembe, Mopani and some parts of Capricorn districts, rainfall is not a constraint as annual rainfall is well above the agriculture and forestry threshold. It is thus recommended that the establishment and expansion of

Agroforestry be carried out in the identified suitable areas and in line with the Department of Agriculture, Forestry and Fisheries Agroforestry 2017 Implementation strategy.

Mr. Jaepil Cho - Climate Change Impact Assessment on Water Balance of Agricultural Reservoirs in Korea - This study was conducted to evaluate the impact of climate change on water balance of whole 3,372 agricultural reservoirs managed by Korea Rural Community Corporation (KRC) in Korea. The downscaled climate change scenario data produced by applying an empirical quantile mapping method to the 60 weather stations in Korea appropriately reproduced the annual cycles of inflow into reservoirs from upstream watershed areas, irrigation water demand from downstream paddy areas and reservoir storage level. HOMWRS (Hydrological Operation Model for Water Resources System) was applied to the single reservoirs and impact assessment was conducted at the branch level of KRC as well as national level. When 3,372 reservoirs were considered at the national level for the Representative Concentration Pathways (RCP) 4.5 scenario during the future period (2011 ~ 2040), inflow, irrigation water demand and water storage level increased by 8.5% (8.25 billion m3), 0.6% (17.88 million m3) and 0.7% (13.9 million m3), respectively. In the case of the RCP 8.5 scenario, they showed an increasing trend of 8.1% (7.82 billion m3), 2.6% (7,583 million m3) and 0.4% (7.27 million m3). However, spatial distribution of water balance analysis at the 93 KRC branches showed the higher increase of inflow and irrigation demand around the north-western and south-eastern region, respectively. As a result, the number of occurrences of storage level less than 50% increased around south-eastern region and it was analyzed that water management will be challenging in this region because of climate changes.

M-C-03: Water reuse and water quality management (I)

Walter Roche - Irrigation Reuse of Wastewater in California, USA - Reuse of wastewater in California, USA has been practiced for over 100 years. The number of sites where it has occurred has grown from 35 in 1910 to over 210 by 2015. The total amount recycled has increased from 175,000 acre-feet per year (AF/Y) in 1970 to 714,000 AF/Y in 2015. Of this total in 2015, 220,000 AF/Y was reused for agricultural irrigation, 126,000 AF/Y for landscape irrigation, and 56,000 AF/Y for golf course irrigation. In addition, 115,000 AF/Y for groundwater recharge and 54,000 AF/Y for injected to combat seawater intrusion provided some benefit for agricultural irrigation. There is potential to double irrigation reuse of wastewater within the next few years. The State Water Resources Control Board (SWRCB) has set goals for reuse of 1,525,000 AF/Y by 2020 and 2,525,000 AF/Y by 2020. Much of this increased reuse is projected to be for irrigation. Drivers for increased wastewater reuse for irrigation include overdraft of groundwater, high salinity and other water quality problems with other local supplies, seawater intrusion, high cost of treatment for discharge to rivers and construction of ocean outfalls, and high cost of imported water. Incentives for reuse include grant and bond funding from state and federal programs, and scarcity of other water supplies. The Integrated Regional Water Management (IRWM) Grant Program is used by communities to implement water supply and management projects which include water recycling projects and is administrated by the State Department of Water Resources. There are two programs administrated by the SWRCB. The Water Recycling Funding Program provides low-interest financing and grants to local agencies and water recycling is a key objective of the program. The Clean Water State Revolving Fund is funded by the Federal Clean Water Act and State Bonds and provides low-interest financing for wastewater collection, treatment, disposal, and recycling projects. Title XVI is a federal program administrated by the U.S. Bureau of Reclamation that provides grants for water reclamation and reuse projects throughout the western United States, including several projects in California. Impediments to greater reuse include safety perceptions, concern about soil and crop health, potential impact on sale of crops, senior water rights for alternative supplies, permits needed for reuse, farmer resistance, and salinity and other water quality factors unsuitable for some crops. The degree of wastewater treatment required depends on the crops that are grown. Crops such as wheat, triticale, and alfalfa are irrigated with undisinfected secondary treated water recycled water. Food crops where the edible portion do not come in contact with the recycled water can be irrigated with disinfected secondary treated recycled water. Food crops where recycled water contacts the edible portion of the crop, including all root crops, can be irrigated with tertiary treated recycled water. In Monterey County, artichokes, strawberries, cauliflower, broccoli and celery are irrigated with tertiary treated recycled water. Similar crops are grown in Ventura County with reverse osmosis added to the treatment train at the Oxnard Wastewater Treatment Plant. There are several other examples of successful reuse projects in California. In San Diego County, recycled water from the City of Escondido is used to irrigate avocados. Some reverse osmosis is added to the treatment train, as avocados are sensitive to high levels of salinity. One of the drivers of this project was the high cost of an ocean outfall for disposal, estimated at $0.5 billion. In Californiaâ€™s Central Valley, recycled water from the Cities of Modesto and Turlock Wastewater Treatment Plants, is conveyed to the Federal Delta Mendota Canal, where it is blended with water from the Bureau of Reclamationâ€™s Central Valley Project. The blended water is then withdrawn by water districts to irrigate nuts, citrus fruit and stone fruit, including peaches, plums, and apricots.

Evan Hillman - Characterizing Drain Water Quality within the Taber Irrigation District, Alberta, Canada - With increasing attention on the quality of drainage water, Taber Irrigation District (TID), with the support of Alberta Agriculture and Forestry, undertook a systematic approach to investigate the effects of surface and drain water sources on receiving waterbodies. Two methods were used to quantify and assess these effects. For one method, a synoptic study followed a parcel of water as it flowed down a canal and measured when and where water quality changed in the canal relative to drain outfalls. For the other method, a survey of water quality from sub-surface tile drainage systems was undertaken within the district. The information collected was used to inform and develop an approval process for drainage system applications within the district. Synoptic sampling was conducted along Taber Lake Lateral canal during run-off and dry conditions at 500-m intervals and from flowing drains. Total nitrogen (N), nitrate-N, nitrite-N, total phosphorus, total dissolved phosphorus, 2,4-D, and Escherichia coli concentrations were higher during run-off than during dry conditions ($p<0.01$). Generally, concentrations increased downstream in the canal. Increased concentrations of total nitrogen, nitrate-N, ammonia-N, total phosphorus, and 2,4-D corresponded with drain outfalls into the canal. These results suggest that beneficial management practice (BMP) and/or treatment options could be considered to improve water quality in drainage water. Water quality samples were collected and analyzed monthly from six tile drain systems within the TID and Lethbridge North Irrigation District. Tile drain water was generally high in concentrations of nitrate-N and salts. Soil characteristics were correlated with tile drain water quality, and subsequently soil phosphate ($r2>0.90$), potassium ($r2>0.71$), pH ($r2>0.76$), and sodium absorption ratio ($r2>0.72$) may be useful in estimating the quality of tile drain outflow. These projects support irrigation managers in the appropriate review and management of drain water and help maintain good water quality in downstream canals for the benefit of water-users and the environment.

Ke-Chun Lin - The Preliminary Study on the Development of Integrated Environmental Monitoring and Pollution Investigation Mechanism in Agricultural Production Environment

Isiaka Toyin Busari - Investigating the effects of ABR wastewater irrigation management techniques on growth and yield parameters of madumbe (Colocasia esculenta) in Durban, Republic of South Africa - The discharge of treated wastewater (TWW) in decentralized wastewater treatment systems (DEWATS) of urban and peri-urban (UP) environments from anaerobic baffled reactor (ABR) effluents can cause pollution. The nutrients available in the effluent have economic importance as a fertilizer where it has the ability to be used for irrigation purposes because such domestic ABRs get input from purely municipal sources, thus the possibility of heavy metals is very low, making ABR wastewater a very promising source of irrigation. The volume of wastewater generated by domestic-municipal sources has increased with population, urbanization, improved living conditions, and economic development. Hence, there is need to utilize the continuous and abundant volume of municipal treated wastewater productively (e.g. irrigation) before safely discharging into water bodies. The performance of madumbe (Colocasia esculenta) to varying irrigation water management techniques using ABR wastewater was investigated in 2017/2018 cropping seasons under field conditions. Therefore, the objective of this study was to evaluate the effects of ABR wastewater irrigation management techniques on the growth and yield of madumbe (Colocasia esculenta)- a water and nutrients demanding crop. A field trial using basin (flood) irrigation with ABR effluent (without fertilizer) was conducted at Pollution Research Group (PRG) farm, Newlands East, Durban, South Africa (S 290 46â€² 26â€²â€² and E 300 58â€² 25â€²â€²). The treatments consisted of alternate wetting and drying (AWD), conventional flooding irrigation (CFI) and continuous wetting without flooding (WWF). It is expected that ABR wastewater irrigation management do have an effect on the yield of madumbe. The treatment with WWF served as control. The experimental setup was randomized complete block design (RCBD) with three replications. The madumbe corm yields for treatments AWD, CFI and WWF were 5.02, 3.29 and 7.52 t ha-1, respectively. The total water used were in the order of 1197, 2033 and 1890 mm for AWD, CFI and WWF while the amount of irrigation excluding rainfall were 850, 1680 and 1540 mm, respectively. The highest average corm yield at WWF was greater than global average yield of 6.5 t ha-1. Madumbe growth parameters (plant height, leaf number and leave area index) were shown to be non-significant ($P = 0.82$, 0.99 and 0.81 respectively). The yield components such as biomass, corm mass, number, size, harvest index and yield were highly significant ($P < 0.001$) among treatments. It is concluded that this study has shown that both AWD and CFI resulted in yield reduction as compared to WWF. This signified the acceptance of the research hypothesis. Therefore, the use of AWD and CFI was discouraged in order to improve the productivity of madumbe, thereby enhancing the potential for food security using ABR water (water reuse) for irrigation. It could be recommended that more household be connected to the sewer in order to increase the volume of ABR effluent for irrigation purposes.

M-A-04: Water-food-energy nexus

Tafadzwanashe Mabhaudhi - Integrating the water – energy – food nexus into national irrigation planning: South African perspectives - Introduction Irrigated agriculture plays a vital role in enhancing food security, and in the curtailment of poverty in developing countries. However, the development of irrigated agriculture to boost food production is challenged by water scarcity, extreme climatic events and change, and energy shortages in South Africa. Addressing this goal sustainably requires an understanding of the interlinkages, trade-offs and synergies between the three sectors, i.e. adopting a water-energy-food (WEF) nexus approach. Although the WEF nexus approach is gaining momentum in South Africa, little effort has been made by the water, energy and agriculture sectors to discourage the â€œsiloâ€• approach. It has been highlighted several times that adopting a nexus approach could ensure water, energy, food and nutritional security by strengthening policy harmonization, policy convergence and enhancing resource use efficiency and mobilization. The objective of this paper was to assess how the WEF nexus approach could be used for planning on irrigation development in South Africa. Methodology We used a set of sustainability indicators to monitor the WEF nexus and then calculated an integrated sustainability indicator for the country that points whether the country is or not in the right path with WEF nexus implementation and development. These include water indicators (Shilling et al., 2013), energy indicators (ForsstrÃ¶m et al., 2011) and food and agriculture indicators (FAO, 1996). A set of models are used to calculate individual WEF resources indicators which are then developed into a single nexus indicator. We calculated the integrated WEF nexus indicator using the UN Statistics method of mathematical integration (UNSTAT, 2017). We also present a trend analysis to indicate different scenarios of WEF nexus adoption for South Africa and how these scenarios can impact irrigation. The present WEF nexus resources situation is presented through a spider diagram of normalized indicator scores. The focus of the integrated WEF nexus indicator indicates the level of interactions, inter-relationships and connections among the WEF resources. These interactions might take the form of interdependencies, constraints and synergies that arise when changes in one area affect others, and they might be viewed as either positive or negative in their impacts.. Results and Discussion Notably, in South Africa, agriculture consumes ~62% of freshwater resources. Although this is already high, the National Development Plan seeks to expand irrigated land by 500 000 hectares; this plan is silent on addressing the full extent of water and energy trade-offs. The driving factors for this plan include climate change, increasing population and affluence, which all necessitate increased and stable food production. However, for South Africa, the WEF resource base is already severely constrained, hence a clear understanding of WEF nexus synergies and trade-offs is essential to future irrigation development planning. There is a need for the water, energy, agriculture sectors to start harmonizing their activities in order to sustain the natural resource base, and to minimize duplication. Based on the current institutional arrangements in South Africa, WEF issues currently play out at different spheres of government, which makes WEF nexus implementation and coordination challenging. There is a key role for national government to set regulatory frameworks and standards, remove policy inconsistencies and bring about alignment, provide funding and technical assistance and facilitate coordination among WEF sectors at different levels of government. National departments will also be essential to integrate the nexus into national strategies, development plans and policy frameworks. Conclusions While there is a clear understanding of the roles played by water, energy and agriculture, existing policies, strategies and plans are still pursuing a sectoral or â€˜siloâ€™ approach. This continues to create disharmony and duplication of activities. Future development and sustainability of irrigated agriculture will require a coordinated WEF nexus. The silo approach in WEF nexus implementation contributes to a negative score for South Africa. The score has potential to improve if more is done to improve WEF nexus implementation,

Vijay Labhsetwar - Actions for green economy through linkages between water, energy and food security - The World, as a whole, has been making steady progress albeit slowly towards improved food security and nutritional status during the past half a century. Humanity is thus still faced with the stark reality of a chronic under-nutrition affecting some 1.02 billion people, more than 20 percent of the population of the developing countries, as many as 37 percent in sub-Saharan Africa and still more in some individual countries. The notion that the world would by now be eliminating the scourge of hunger and under-nutrition has so far proven overly optimistic. The role of Water Resources Development (WRD) is going to be increasingly important with growing population and declining world food grain production, since food yield response to irrigation is almost double as compared to rain-fed agriculture. Human societies will continue to rely on areas under irrigation for food security. Presently 280 million ha of land is irrigated accounting for 18 per cent of total arable and cropped area (1554 Mha) in the world. This means that crops are grown on 1084 Mha without a water management system (drained lands 190 Mha). Therefore, there is tremendous scope to increase area under irrigation by way of more storage dams, where possible, specially in Asia and Africa. Further, potential irrigation demand will grow in developing countries, while it will actually decline in developed countries. The fastest growth in potential demand for irrigation water will occur in Sub-Saharan Africa and in Latin America. Each of these regions has a high percentage increase in irrigated area from a relatively low 1995 level. Unless, the aforementioned irrigation potentials are developed, population expansion will force millions of impoverished people to undertake unsustainable farming systems. The country case studies suggest the following issues / approaches / policies that could be considered responsible for achieving food security: (1) restructuring of the public finances; (2) conducive institutional framework; (3) research and dissemination of new technologies; (4) emphasis on antipoverty policies; (5) holistic approach to agriculture; (6) provision of irrigation and high yielding varieties, fertilisers and pesticides; and (7) extensive social safety nets etc.

Ahmed Abdelkader - Dynamic water, food, and trade modeling: case study for Egypt - The socioeconomic developments demands for water and food are challenged by the spatiotemporal variability in climate and water availability. Traditionally, humans relied on water resources management of storage and control structure to distribute water in times and places of shortages. However, water resources management is considered spatially limited when compared with the distribution of virtual water, which crosses watersheds and even continental boundaries. The global food trade makes all countries share their water resources, and hence, necessitates the consideration of virtual water in national water planning and decision making. The anticipated future food gap in a country and water scarcity problems require considering future scenarios of changing national virtual water trade in the context of future global virtual water trade scenarios. In this study, we introduce a national water, food, and trade modeling framework (NWFT) for the analysis of real and virtual water at the national scale. The framework has two components: (1) a national water-food supply and demand model; and (2) an international virtual water trade model. The national model captures the compound effect that the population growth has on water and food demands. The model estimates the available water supply for various uses, and hence, any water and food gaps can be quantified. Consequently, the potential food import and export is estimated. Finally, Food trade is expressed in water units (i.e. virtual water) to calculate the national virtual water trade. In parallel, the international virtual water trade model simulates the global virtual water trade network, and is used to estimate the national virtual water trade based on global variables. The two models can be compared for any discrepancy that requires the attention of decision-makers at the national scale. The application of the model starts with a snapshot of the baseline period and then projects national and global future scenarios. The model was applied to the case study of Egypt, a water-poor country that imports 40% of its cereals consumption. Egypt's water and food gap were analyzed in the baseline period (1986-2013) and under four national and five global future scenarios up to the year 2050. The results indicated a widening food and water gaps that are driven by the high population growth rate and a water-constrained food production system. Both the national and the international model components projected similar trends for Egypt's food gap. The Sensitivity analysis results reflected the fact that the solution of water scarcity might not be limited only to water-based solutions, but also a combination of policy intervention and societal adaptation, such as lowering the population growth rate. The modeling framework can be easily applied to other countries. The approach of analyzing water in its real and virtual forms, rather than only one of them, can be a useful approach to quantify the water-food (and perhaps energy) nexus and bridge an important gap between water resource managers and policymakers at the national level. Furthermore, the study also provides a way for policymakers at the national scale to benefit from the emerging research in global virtual water trade.

Lina Wu - An Integrated Model for Dynamic Assessment of the Food-Energy-Water nexus in Saskatchewan - "Food, energy, and water (FEW) security is a key challenge in the world where millions of people still lack access to enough food, clean water, and reliable electricity. Pressure on FEW resources will be exacerbated by population growth, climate change, and dietary changes. Thus, an approach to meeting the resource demand, while minimizing conflicts among sectors is needed. The FEW nexus analysis and modeling are presented as a method, which has the potential to effectively manage limited water, land, and energy resources by reducing inter-sectoral trade-offs while increasing synergies as well as resource use efficiency. In the nexus, the output from one component can be an input to another component (e.g., food waste and straws as feedstock for bioenergy production, while treated wastewater can be used for irrigation). The prerequisite to manage FEW resources is to understand the inevitable interconnections and feedbacks among food, energy, and water. In this study, an integrated modeling framework based on system dynamics (SD) is developed to assess the FEW nexus in the province of Saskatchewan, Canada. The SD modeling framework allows for investigating the interactions, feedbacks, and trade-offs within the system composed of the three subsystems of food, energy, and water resources. The model includes components that account for the production and consumption of food and energy. Available water resources, consisting of all blue water (surface and groundwater) as well as green water, are included to dynamically supply water for both food and energy production while meeting all other water demands (e.g., municipal and environmental uses). The model reveals the complex interdependencies and competition in food and energy for water and land resources. For example, the reduction of fossil fuel-based electricity generation from the current share of 75% to 50% of total electricity production by 2030 in Saskatchewan will decrease water demand for thermal power cooling. However, land requirements for renewable energy production (e.g., wind and solar power as well as biofuel) that replaces thermal power will increase. In addition, expansion of bioenergy production from wheat and canola will decrease their availability as food supply, which leads to decreasing agricultural exports or even importing from other countries. The developed model can estimate the present and project future food and energy production and demand as well as water supply-demand, driven by population growth and economic development scenarios. Impacts of policies, such as enhancing local renewable energy sources and irrigation expansion, on the FEW nexus and greenhouse gas (GHG) emissions are also assessed. To assess resource sustainability, self-sufficiency of food, energy, and water are quantified during the historical period (1986-2014) as well as under future scenarios. The model can be easily expanded to multiple scales, starting from provincial or watershed scale to regional or national scale to inform decision-makers at different levels."

M-B-04: Climate change and its impact on agriculture, irrigation, and drainage (II)

Ms Saowanit Prabnakorn - Drought hazard to rice cultivation in the Mun River Basin, Thailand - Approximately 60% of rice fields in Thailand are in the northeast, where about 90% of that is rain-fed. The rice here usually experiences droughts resulting in the lowest productivity of the country. Therefore, the understanding of the extent of droughts to rice cultivation is essential for appropriate water management. The study investigated drought hazard by developing the new approach based on water deficit. The analysis was conducted at the Mun River Basin, Thailand at monthly time step. The results show that monthly precipitation during the rice-growing season is insufficient to meet rice water requirement at all stages of rice growth. The hazard is more severe in November and October. In November, rice is under the high level of drought hazard, but the impacts of droughts are less at this ripening stage. In October, rice is at flowering and grain-filling stages, which is highly vulnerable to drought. The hazard is at the high level in the upper part of the basin, and at the moderate level in the lower part. In September, August and July drought decreases from west to east. September has the least water deficit because of highest precipitation. In August, drought reduces the number of tillers and panicle, which result in lower yields. The rainwater in July is for land preparation, thus drought will postpone the onset of the growing season. These findings emphasize the importance of the agricultural drought assessment at monthly time step because the hazard map of total precipitation over the growing season demonstrates only moderate and low levels implying that the total precipitation is not far less to fulfill the growth demand. Our results provide useful information regarding droughts at each stage of rice growth in the basin in Thailand, which can assist the relevant people in water management to enhance the yield.

Nozar Ghahreman - Possible effects of climate change on cropping pattern in northeast of Iran: A climate smart approach - "Water and food security are the major challenges under climate change as both are highly vulnerable to continuously changing climatic patterns. Food and Agriculture Organization of the United Nations (FAO) has proposed the Climate Smart Agriculture (CSA) as an integrative approach to address interlinked challenges of food security and climate change. The aim of this study is investigation the possible effect of climate change on development and evapotranspiration of Wheat, Maize, Barley crops in northeast of Iran, i.e Khorasan provinces under AR5 climate change scenarios (IPCC AR5 RCP scenarios) for future period of 2091-2100.The climate projections used for the study were EC-EARTH global climate model projections which were dynamically downscaled by Swedish Meteorological and Hydrological Institute (SMHI). The observed climatic data of 7 synoptic stations in this provinces, were used to calibrate model downscaled data. After calibrating, the changes of precipitation, crop evapotranspiration and length of growing season of two crops (wheat and maize) were studied for different date of sowing with 10 days interval according to local crop calendar and recommendations.The length of growing season was calculated using GDD approach (The total required heat units). The results of study showed that the amount of precipitation during wheat growing season, in all study stations, would reduce, while the evapotranspiration will remain almost same with baseline period values. Therefore, continuous cultivation of wheat in the region during the future period cannot be recommended. Based on the results, the climatic condition during maize growing season will not significantly change except for two stations of Bojnord, Birjand. Also in most of the cases, postponing the date of sowing for 20 days from current dates, would be more favorable for study crops. Considering the obtained results, continuous cultivation of wheat cannot be recommended due to limited available water in selected stations. In an attempt to propose a more climate proof cropping pattern and suggesting alternative crops to be grown in study regions under future climatic conditions, thermal requirements, evapotranspiration and length of growing season of barley crop were studied with same methodology applied for the other two major crops used in baseline period. In general, there is no significant improvement in agroclimatic conditions for this alternate crop comparing to those currently cultivated,hence employing water saving measures and increasing water productivity should be considered. There might be some water shortage for wheat which is the dominant crop grown in the region. Further studies in other climatic regions of the country are recommended for more scrutiny."

Ms Luciana Cunha - <u>Drought Vulnerability Assessment for the Middle Rio Grande</u> - The Middle Rio Grande Conservancy District (MRGCD) operates, maintains and manages irrigation, drainage and river flood control in the Middle Rio Grande (MRG) Valley in New Mexico, USA. MRGCD acknowledges that droughts are already a threat to agriculture in the region and that climate change combined with population growth can aggravate the problem even more. To mitigate the impacts of droughts, MRGCD is evaluating drought vulnerability under past, current, and future scenarios as well as exploring possible mitigation strategies. In this presentation the drought vulnerability assessment being developed for MRGCD will be discussed. The main goals of the project are: (a) to develop a better understanding of the hydro-meteorological conditions that cause droughts; (b) to evaluate how current droughts compare to droughts that have happened during the paleoclimatic record and droughts that can potentially happen in the future under climate change; (c) to develop operational methods for the early detection and quantification of droughts, (d) to establish drought triggers that are directly linked to actions that can minimize the impacts of droughts, and (e) to identify opportunities for MRGCD to maximize the use of its water supply under changing conditions. For brevity, in this abstract we focus on the first part of the project which consists of evaluating an expected range of drought conditions. The Rio Grande basin is a large and complex catchment. Runoff at the basin headwaters is controlled by alpine snow melt, while the low elevation desert regions in the downstream parts of the basin depends on runoff generated as the result of short duration scattered convective rainfall events. We also limit our discussion to the Rio Grande headwater contributions to water supply, which constitute the major source of water for MRGCD. Instrumental records of streamflow usually date back about 100 years. This period of record does not provide a complete picture of the full range of variability in climate. Tree-ring datasets extends back hundreds and even thousands of years and therefore provide valuable additional information on the length and severity of past droughts. Reconstructed time series of natural streamflow are available for the Rio Grande Basin at Otowi Bridge (Woodhouse et al. 2012). This location is used to monitor the Rio Grande inflow into the MRG valley of New Mexico. Annual inflows vary between 23% and 238% of the long-term average. The 5-year moving average shows significant variability within the basin storage capacity window. The wettest 5-year period occurred between 1982 and 1987 A.D. when the 5-year average inflow was 53% higher than the long-term average. The driest period occurred between 1663 and 1668 when the 5-year average inflow was 45%

lower than the long-term average. The period of 1999 to 2004 was also extremely dry with average inflow 43% lower than the long-term average. No clear trend is observed during the period of data. The probability of non-exceedance for the driest 5-year period that occurred during the observed period of data was calculated based on the observed (P1) and the paleoclimatic records (P2). The 5-year inflow observed during the drought of 2004 has a probability of occurrence of 0.24% based on P1, and 6.34% based on P2. These significant differences demonstrate that the observed record underestimates the likelihood of severe droughts conditions. BCSD-CMIP5 climate and hydrological projections were analyzed to understand possible climate change impacts on droughts (Reclamation, 2014). In this report, we investigate the representative concentration pathways (RCP) 4.5 and 8.5 for the 10 models selected by the California Department of Water Resourcesâ€™ (DWRâ€™s) Climate Change Technical Advisory Group (CCTAG). CCTAG selected models based on how well they represent historical climate at the global and Western United States scales. The major potential changes for the Rio Grande Basin include: - Warmer temperatures and higher potential evapotranspiration: For the second half of the 21st century, maximum temperatures are expected to be 30% (5ºC) higher and potential evapotranspiration increases by 16% for RPC 8.5. For RPC 4.5, increase in evapotranspiration occurs during all months, while for RPC 8.5 increases occurred specially from February to May, and a decrease is observed for June and July; - Timing of precipitation: No significant change in precipitation was detected at the annual level. At the monthly scale, precipitation trends in April, May, and October are slightly negative for RPC 4.5 and 8.5, while in August a positive trend is detected for both scenarios; - Decreased and altered timing of runoff: Annual total runoff decreases for both scenarios. At the monthly scale, runoff increases for March and April, and decreases for May and June. That is a direct result of snowmelt happening earlier in the season due to higher winter and spring season temperatures. Inter-annual variability of flows will also increase, which will result in an increase in the frequency, intensity, and duration of both droughts; - Changing soil moisture: As a result of higher potential evapotranspiration, average soil moisture decreases for all months. The decrease in soil moisture availability will strongly affect agriculture in the region; - Increase severity of droughts over longer periods: Projections indicate that droughts will become more frequent and more intense. For example, during a period of 5-years average runoff is projected to be as low as 65% of the observed average. As a reference, the worst drought experience during the paleoclimatic record was the result of average inflow 45% lower than the average. New Mexico's water resources have been stressed by periodic droughts. The MRGCD is developing a drought contingency plan to minimize drought impacts by better identifying, quantifying, preparing, responding, and recovering from droughts. A drought contingency plan requires methods to efficiently and accurately identify and quantify droughts. Droughts of different intensities should be directly linked to drought action levels, and appropriate agency responses. In this project, Global Climate Circulation model projection and paleoclimatic datasets are used to obtain a complete picture of possible drought severity, frequency and duration in the area, and to define the actions that can be taken by the district to minimize the impact of extreme events. While the region has always struggled with periodic drought, current climate projections raise the possibility that in the future drought frequency and severity could increase in the Middle Rio Grande Basin. References Woodhouse, C. A., D. W. Stahle, and J. Villanueva-D î€, Ä±az (2012), Rio Grande and Rio Conchos water supply variability over the past 500 years, Clim. Res., 51, 147â€“158, doi:10.3354/cr01059 Woodhouse, C. A., D. W. Stahle, and J. Villanueva-D î€, Ä±az (2012), Rio Grande and Rio Conchos water supply variability over the past 500 years, Clim. Res., 51, 147â€“158, doi:10.3354/cr01059 Woodhouse, C.A., D.W. Stahle, and J. Villanueva-DÃaz. 2012. Rio Grande and Rio Conchos water supply variability from instrumental and paleoclimatic records. Climate Research.51, 125-136. doi: 10.3354/cr0105 Reclamation, 2014. 'Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections: Release of Hydrology Projections, Comparison with preceding Information, and Summary of User Needs', prepared by the U.S. Department of the Interior, Bureau of Reclamation, Technical Services Center, Denver, Colorado. 110 pp."

M-C-04: Water reuse and water quality management (II)

Cheng-Chi Lin - Application of Resin Capsules in Heavy Metal Monitoring in Irrigation Water - "In the past few decades, due to industrial development, many factories were scattered around the farmland, some agricultural land was threatened by industrial wastewater pollution in Taiwan. The wastewater discharged from factories containing heavy metals, which have caused damages to agricultural production and endangered food safety and human health. In order to monitor the water quality of the agricultural production environment, many efforts were made, however, grab sample cannot represent actual water quality and chemical analysis costs were expensive. In view of this, in this study, ion exchange resin capsule was developed which has fast and powerful ion exchange capacity, high efficiency, fast reaction and low cost while used to detect heavy metals in water. Through the jar test in the laboratory to make standard samples of resin with different adsorption concentration, and then we established the resin detection module for the X-ray Fluorescence Spectrometer (XRF). The ion exchange resin packages were called ion exchange resin time-lapse capsules. They can be placed at the specific points in the field and then taken back after few days, to continuously monitor heavy metals released into the environment during this period. For the in-situ experiment, total 671 resin capsules were used in the test area in Taoyuan. There were many elements absorbed by resin capsules and the ratio of Sr and Ca was 0.011 showed that there was stable content in water. There were still similar stable ratios in other regions so that Ca or Sr can be used as a reference for water flow through the resin capsules and the standardization ratio (Cu/Sr and Zn/Sr) can be the indicator of pollution. Using the relatively high and low values of the indicators can find out the points that need more attention in the field. Practically used in irrigation channel located in high potential pollution area, Changhua, many resin capsules were put in the field, and take back after 7 days. The results showed that resin capsules can continuously monitor heavy metals released in water and they can quickly, effectively distinguish hot spots where heavy metals discharged. This method is a great weapon for providing scientific evidence of illegal intermittent discharge with heavy metal discharged in nighttime or holiday."

Chihhao Fan - Forewarning analysis of the irrigation water quality by linking automatic monitoring system - In Taiwan, there were 746 acres of agricultural farmland (the total number of 4,402 pollution incidents) that had been declared against agricultural growing activities due to heavy metal pollution by the end of 2013. In order to obtain immediate irrigation and drainage water quality monitoring information, the present study introduced an automatic water monitoring system to improve the immediate readability of temporal-spatial data. All the observed water quality variation can be visualized through combining the presentation platform of geographical information system. Finally, this research proposed the forewarning framework of water quality abnormality through automatic monitoring system, which can be an important reference for decision makers of governing agencies.

Dr. Eman Ragab - The national water quality monitoring network in Egypt: Assessment and rationalization approach - Food, energy, and water (FEW) security is a key challenge in the world where millions of people still lack access to enough food, clean water, and reliable electricity. Pressure on FEW resources will be exacerbated by population growth, climate change, and dietary changes. Thus, an approach to meeting the resource demand, while minimizing conflicts among sectors is needed. The FEW nexus analysis and modeling are presented as a method, which has the potential to effectively manage limited water, land, and energy resources by reducing inter-sectoral trade-offs while increasing synergies as well as resource use efficiency. In the nexus, the output from one component can be an input to another component (e.g., food waste and straws as feedstock for bioenergy production, while treated wastewater can be used for irrigation). The prerequisite to manage FEW resources is to understand the inevitable interconnections and feedbacks among food, energy, and water. In this study, an integrated modeling framework based on system dynamics (SD) is developed to assess the FEW nexus in the province of Saskatchewan, Canada. The SD modeling framework allows for investigating the interactions, feedbacks, and trade-offs within the system composed of the three subsystems of food, energy, and water resources. The model includes components that account for the production and consumption of food and energy. Available water resources, consisting of all blue water (surface and groundwater) as well as green water, are included to dynamically supply water for both food and energy production while meeting all other water demands (e.g., municipal and environmental uses). The model reveals the complex interdependencies and competition in food and energy for water and land resources. For example, the reduction of fossil fuel-based electricity generation from the current share of 75% to 50% of total electricity production by 2030 in Saskatchewan will decrease water demand for thermal power cooling. However, land requirements for renewable energy production (e.g., wind and solar power as well as biofuel) that replaces thermal power will increase. In addition, expansion of bioenergy production from wheat and canola will decrease their availability as food supply, which leads to decreasing agricultural exports or even importing from other countries. The developed model can estimate the present and project future food and energy production and demand as well as water supply-demand, driven by population growth and economic development scenarios. Impacts of policies, such as enhancing local renewable energy sources and irrigation expansion, on the FEW nexus and greenhouse gas (GHG) emissions are also assessed. To assess resource sustainability, self-sufficiency of food, energy, and water are quantified during the historical period (1986-2014) as well as under future scenarios. The model can be easily expanded to multiple scales, starting from provincial or watershed scale to regional or national scale to inform decision-makers at different levels.

Tuesday, 14 August

Session	Presenter(s)	Title
T-A-01: Irrigation & water resources management in transboundary basins	Jilllian Brown Syed Mustakim Ali Shah Jong Won Do	Irrigation Development as an Instrument for Economic Growth in Saskatchewan: An Economic Impact Analysis Investigating the vulnerability of irrigated agriculture across the Saskatchewan River Basin under different future scenarios Optimal irrigation management system based on hydraulic analysis of irrigation channel
T-B-01: Climate change and its impact on agriculture, irrigation, and drainage (III)	Graham Parsons Shiang-Min Chen Laurie Tollefson Shervan Gharari Abraham Joel	Lake Diefenbaker, Saskatchewan Canada. A Visionary 20st Century Start on 21st Century Issues. CO2 Emissions of Rice Observed from A Paddy Field Under System of Rice Intensification Irrigation in the Context of Climate Change in Canada Estimating near-surface soil moisture under climate change using an improved configuration of the Variable Infiltration Capacity (VIC) model based on Grouped Response Units (GRU) Assessing the irrigation demands in Sweden under changing climate
T-A-02: Irrigation & water resources management in transboundary basins AND Managing competing water demands (I)	Session Cancelled	
T-B-02: Climate change and its impact on agriculture, irrigation, and drainage (III) AND Irrigation water footprint (I)	Charles Nhemachena Jianxin Mu Cara Drury Margo Redelback	Review of climate change and variability impacts on water resources, irrigation and agricultural sector performance in Southern Africa Irrigation Certification in Saskatchewan Irrigation Certification in Saskatchewan Alberta Irrigation Sector 2005-2015 Conservation, Efficiency and Productivity Plan and Evaluation
T-A-03: Managing competing water demands (II)	Caren Jarmain Carl Walters Sitti Rahma Ma'mun Muhammad Usman Rashid	Remote sensing, Machine Learning and Water Accounting: New-age tools to support and age-old challenge Managing competing water demands through a partnership approach in Northern Victoria, Australia Alternative institutional arrangement for sustainable irrigation: a study of local water users association in Indonesia Formulating diagnostic assessment and modernization approach for large irrigation systems
T-B-03: Irrigation water footprint (II)	Jiabin Wu Amali Abraham Amali Haili Wang Pilar Gil Christopher Neale	Quantification of alfalfa water uptake from different layers and root zones under drip irrigation using stable hydrogen Assessment of crop water use and stress using multidate satellite data Study on Water Demand and Suitable Soil Water Content of Banana, Guangdong , China Strategies for reducing water consumption in vineyard grapevines without affecting water status, yield and wine quality. Application of remote sensing to evaluate the spatial-temporal variation in irrigation performance in Central Nebraska, USA
T-A-04: Managing competing water demands (III)	Leila Eamen Mohammad Ghoreishi Andrew Slaughter Khaled Akhtar Clarke Ballard	An Evaluation of Current and Future Water Allocation Strategies in the Saskatchewan River Basin, Canada Improving Resilience of Water Resources Systems through Public Awareness: The Key Role of Media in Affecting Agricultural Water Use Water resources management modelling for achieving equitable sharing of water within the Saskatchewan River Basin Bow River Sim – A Serious Game for Communicating Bow River Integrated Water Management Competition for irrigation water - Case studies
T-B-04: Drainage and flood control strategies (I)	Heidi Salo Olle Häggblom Helena Äijö Christopher Gallagher	Assessing the difference between trencher and trenchless subsurface drainage methods through groundwater level observations Impacts of supplementary drainage on the water balance of a poorly drained clayey agricultural field The effect of supplementary subsurface drainage on nutrient and sediment loading in clay soil Integrating Taber Irrigation District into our Watershed: More than Mitigation

T-A-01: Irrigation & water resources management in transboundary basins

Jilllian Brown - Irrigation Development as an Instrument for Economic Growth in Saskatchewan: An Economic Impact Analysis - Allocation decisions in Saskatchewan of water are needed because of the limited nature of the resource in the province. Timely allocation of water can impact crop production, and through that economic development in the province, which may result through the value of the improved crop production as well as the economic linkages within the economy. Irrigation can be seen as a tool for economic growth as it decreases the reliance on natural factors which are critical for crop production in the province. The provincial government has committed, among its various agricultural initiatives, to develop tools to reach economic development goals. A study of the economic importance of irrigation in Saskatchewan is important to understand its contribution provincially and regionally as a possible tool for this economic development. The economic impacts of irrigation extend beyond farm-level impacts and understanding how it contributes to the entire economy at a provincial and regional level is information needed by decision makers. The purpose of this study is to provide the contributions of the irrigation sector on the provincial and regional economy. The Saskatchewan Irrigation Impact Analyzer (SIIA) model was built as a part of this study. The SIIA was based on a regionalized rectangular input-output model of the irrigation sector. Base data for the model were obtained from Statistics Canada Transaction Tables for 2011. The model was regionalized into: The Lake Diefenbaker Development Area (LDDA) and the other regions of Saskatchewan. The original data for agriculture production were disaggregated into irrigated and dryland production, each further disaggregated to crop and livestock production sectors. The model was further augmented with an employment model. Two scenarios of irrigation development were tested in the study: First, irrigation development that occurred during 2011-2016; Second, new irrigation development through infill expansion. In addition, the marginal contribution of the irrigation activity on the lake Diefenbaker Development Area region was also undertaken, which required a survey of producers. The study found that the total economic impacts of irrigation development during 2011-2016, enabling an additional 8,472 acres of irrigated production, amounted to $200.83 million in output (sales) generating $86.60 million in GDP contributions at market prices. This resulted in 1,179 full-time equivalent (FTE) employment years and $62.48 million in household income contributions. These estimates are based on a simulation of irrigation over a twenty-year period. With respect to potential irrigation expansion, the study found that if the 32,250-remaining infill-acres (that have been identified as offering irrigation potential) were to be developed and under production for a twenty-year period, the total economic impacts to the province of Saskatchewan would be $603.70 million in output (sales) responsible for 2,908 FTE employment years. This would amount to $181.12 million in household income contributions and $240.89 million in gross domestic product (GDP) contributions at market prices, at 2011 dollars. The study also found that regionally, irrigation provides an impetus for economic development. During the 2011 year, the marginal contribution of irrigation production, over and above the alternative of dryland production, was created through purchases of higher amounts of farm inputs, as well as spending of additional household income. These two avenues resulted in total economic impacts of $116.53 million in output (sales) which generated $78.47 million in GDP contributions at market prices. In the region, $58.72 million in household income gains also were incurred as a result of the 1,323 FTE employment years generated. The study found the economic impacts of irrigation, currently and potentially, to be extensive in each scenario and offering considerable regional impacts over and above the dryland production alternatives.

Syed Mustakim Ali Shah - Investigating the vulnerability of irrigated agriculture across the Saskatchewan River Basin under different future scenarios - The Saskatchewan River Basin (SaskRB) is a large, multi-jurisdictional river basin that spans the Canadian provinces of Alberta, Saskatchewan, and Manitoba and the US State of Montana, and is a key water resource for these prairie regions. A major portion of Canadas agricultural area is located in this basin, mostly in southern Alberta; therefore, the SaskRB, plays an important role in countrys economy. The South Saskatchewan River is the only major source of water for irrigation in southern Alberta and 86.5% of extracted surface water is used for agriculture, which is primarily responsible for periodic water stress in this region. Moreover, agricultural land use in the Prairie Provinces continues to evolve and limited water resources could pose a threat to the sustainability of agriculture, particularly since water has to be shared with environment and other economic sectors that are water dependent. In addition, climate change impacts that are already evident in Western Canada could increase the future variability of precipitation, evaporation, snowmelt, soil moisture, and runoff. These changes in the hydrological system might affect future irrigation demand and crop productivity. In Canada, the provinces are primarily responsible for water management, which has resulted in water management according to political rather than catchment boundaries. Sharing of water in the SaskRB between the provinces has therefore been facilitated by the Master Agreement in Apportionment (1969) and complex operating policies have resulted in the provinces adopting their own models for water management and decision making, resulting in fragmented water management. Increased development, along with increased hydrological variability due to climate change, are likely to further complicate the process of water management in the SaskRB. This increased complexity in water management and possible future shortcomings of the apportionment agreement, particularly under water stress conditions, highlights the need for basin-wide integrated water resources management. The aim of this study is to integrate water demands across the entire SaskRB into one modelling platform, in line with the aims of the Integrated Modelling Program for Prediction and Management of Change in Canadas Major River Basins (IMPC), with a focus on investigating the anticipated risk of irrigated agriculture and associated water management options under a range of future scenarios. For this purpose, we use the MODSIM-DSS software package, developed for river basin water management and decision support. We emulate the current physical system within this model and validated it by comparing the model results with that of the Water Resources Management Model (WRMM) presently used by Saskatchewan Water Security Agency (WSA) and Alberta Environment and Parks (AEP). We run this integrated model under a range of future scenarios of hydro-climate change and irrigation expansion to assess the vulnerability of the water resources system under different conditions. For future hydro-climatic scenarios of this region, we utilize the research outputs of Changing Cold Regions Network (http://ccrnetwork.ca/) that provide a rigorous assessment of change in the hydrologic regime of SaskRB over the 21st century. The results of this study provides insights into vulnerabilities of the system and the viability of the planned irrigation expansions across the basin.

Jong Won Do - Optimal irrigation management system based on hydraulic analysis of irrigation channel - Recently, in South Korea, the occurrence of droughts frequently occurs due to the regional local precipitation phenomenon related to climate change, the necessity of reducing the amount of water loss through optimum water management is increasing.Therefore, it is necessary to analyze and apply a water supply system that minimizes water loss through scientification and quantification of the supply and management of agricultural water. In this study, we constructed a network of water supply systems in a single reservoir irrigation area based on the SWMM (Storm Water Management Model). The SWMM can reduce the use of extra agricultural water through the required quantity of reservoirs, the optimum water supply quantity for each irrigation system, the number of water supply days, etc.

T-B-01: Climate change and its impact on agriculture, irrigation, and drainage (III)

Graham Parsons - Lake Diefenbaker, Saskatchewan Canada. A Visionary 20st Century Start on 21st Century Issues. - N/A

Shiang-Min Chen - CO2 Emissions of Rice Observed from A Paddy Field Under System of Rice Intensification - Greenhouse gas emission from paddy fields has been influenced by climatic or environmental conditions. The whole-canopy gas exchange technique was adapted to provide accurate measurement of CO2 emission and other weather data to compare the single-leaf measurement. Four different levels of water irrigations: SRI2cm, SRI3cm, SRI4cm and SRI5cm were implemented in plots of 6 m2 in the experimental site of National Pingtung University of Science and Technology located in Southern Taiwan. Irrigation schedule was maintained in the plots according to each treatment. Data were measured starting from 2nd February 2018 to 5th May 2018; the CO2 emission was monitored every 7 days, during the vegetative and reproductive stages. The important data about the emissions of CO2 and H2O in the paddy fields were measured by the Whole Plant Photosynthesis (WPP). These parameters were used to establish effective relationships between CO2 emission and water consumption in the paddy field. the average CO2 emission in the reproductive stage was higher than vegetative stage, which confirms the confirm the expectation.

The grain yields under SRI3cm, SRI2cm presented the high yield then SRI4cm and SRI5cm, data showed respectively 3080 Kg/ha and 2604 Kg/ha. The CO2 emission under SRI3cm was lowest than SRI2cm, SRI4cm and SRI5cm presented the same range of CO2 emission. The results confirmed that SRI3cm could obtain comparable grain yield close to farmer practices less irrigation. These findings suggested that the SRI with 3 cm water depth (SRI3cm) could be used for water-saving and greenhouse gases mitigation while maintaining grain yield in SRI production.

Laurie Tollefson - Irrigation in the Context of Climate Change in Canada - An adequate supply of good quality water is required for agricultural production. Globally and in Canada growing populations, urbanization, pollution, changing weather patterns, etc. put pressure on a limited water resource. Although Canada is considered a water rich country most of its water is not located near major population centres. Canada`s five largest drainage regions provide 55% of the annual water supply but are home to only 8% of our population. Important agricultural regions of western Canada have much lower supplies. There are serious risks of future reductions in water availability on the prairies, where 80% of Canada`s farmland is located. Increasing water use efficiency is a critical tool for resilience in these drought prone areas. Drought has a very high cost for the Canadian economy and for Government budgets. Approximately 90% of the fresh water used in Canada is used for irrigation of crops. Irrigation is practiced on one million ha of Canada`s 44 million ha of arable land. Eighty percent of the irrigated land is in the semiarid regions of western Canada, though there is some agricultural irrigation in every province. Irrigation is a key tool supporting drought mitigation, crop diversification, economic development, and value adding. A recent study commissioned by the Alberta Irrigation Projects Association found that every cubic metre of water delivered raises the Alberta Provincial GDP by CAN$3.00 and labour income by $2.00. Alberta's irrigated land is only 4.7% of it cultivated land, but generates 20% of its Agriculture and Food GDP. The irrigation industry in Alberta contributes $3.6 billion annually to the provincial GDP. Evidence for global warming is unequivocal. Extreme weather events and greater weather variability are forecast to be the new normal. Periods of extended drought and flooding are to be expected. Climate models vary, but most predict a 2.5-4.0Â°C increase in temperature and a 2-10% increase in precipitation in the Canadian Prairie region. Any benefits of increased precipitation may be eclipsed by increasing evapotranspiration, reduced soil moisture, and a much increased moisture deficit resulting from higher temperatures. The spatial and temporal distribution of water resources will be altered. Increased water scarcity is predicted in many regions of western Canada due to the climate change and increasing demands from other water users. Climate change effects on future hydrology will stress irrigation, drainage, and flood control infrastructure and resources. Agricultural water management including irrigation and drainage will be key components in adaptation to climate change. Improving water use efficiency while maintaining water quality will be critical. That will require engineering, agronomic, and institutional approaches. AAFC `s role in agricultural water management includes research, development, and technology transfer to provide economic, environmental, and social benefits. AAFC should conduct research into fundamental processes, develop decision support tools, and transfer technology to support on-farm adoption of Beneficial Management Practices (BMPs) for irrigation, including: 1) Evaluation of new and existing crops and varieties under irrigation 2) Development of BMPs for sustainable irrigated production (e.g. agronomy, greenhouse gas reduction and mitigation, season extension) 3) Evaluation of irrigation management practices for improved water and energy use efficiency and resource protection (e.g. precision or variable rate irrigation, irrigation scheduling methods, surface and subsurface drainage) 4) Technology transfer Responsibility for water management in Canada is shared by the federal, provincial, and municipal governments, and in some cases territorial and aboriginal governments as well. The provinces have primary jurisdiction over most areas of water management and protection. Partnerships are thus key to meeting objectives and mandates related to agricultural water management. Industry is important in contributing to setting priorities and policy direction, and participating in technology transfer and funding. Academia plays important roles in research and teaching. Collaboration within partnerships is needed to address the priorities. The Canada-Saskatchewan Irrigation Diversification Centre at Outlook, SK is such a partnership. Here a federal-provincial-industry-university partnership is in place to collaborate in research, demonstration, and technology transfer in support of the irrigation industry. Many experts believe that western Canada could be one of the few areas on earth to benefit from climate change. The additional heat units and longer growing season may allow production of higher valued crops, but only if producers are able to adjust by adopting suitable crops and technology. The agricultural industry is currently not well prepared to deal with climate change. Clearly awareness needs to be enhanced. A concerted effort by government and industry will be required.

Shervan Gharari - Estimating near-surface soil moisture under climate change using an improved configuration of the Variable Infiltration Capacity (VIC) model based on Grouped Response Units (GRU) - Canadian river basins are facing rapid changes such as increase in water demand for irrigation, land cover changes, permafrost thaw and glacier melt. Prediction of future conditions such as soil moisture content under both climatic and anthropogenic changes are of significant importance for decision makers. To assist decision makers, a large-scale, integrated modeling approach which takes into account both climatic and anthropogenic changes is essential. We use the Variable Infiltration Capacity (VIC) model as a simple land surface model. We develop a computationally efficient VIC model configuration that explicitly accommodates all the information on soil, vegetation, elevation and forcing data. Unlike the traditional VIC setup, our VIC configuration is based on Group Response Units (GRUs) with unique land cover, soil type, elevation and forcing data. These GRUs are not necessarily regular grids. The VIC-GRU is set up for 23 nested basins of the South Saskatchewan River Basin. Irrigated agricultural land is dominant land cover of nested test basins. To evaluate top moisture content changes under climate change, the model is forced and calibrated for the current and past climate conditions using WFDEI (WATCH-Forcing-Data-ERA-Interim) data set. The future top soil moisture content by the end of century is then simulated using the calibrated model forced with bias corrected Can-RCM4_RCP8.5 based on WFDEI data set. Although VIC-GRU does not include irrigation explicitly into account, the comparison of the soil moisture contents from the current and future climate scenario will reflect on possible soil moisture deficit for agriculture in the growing season.

Abraham Joel- Assessing the irrigation demands in Sweden under changing climate - In Sweden as many other countries, the agriculture sector is developing adaptation plans to counter act the effects of climate change. For this reason an assessment was carried out in order to quantify how irrigation demand in Sweden has change during two historical periods, 1961-1990 and 1991-2016 and what will be the changes in the future for the next coming 30 years, 2021-2030. In order to assess irrigation demand, a water balance was calculated in three different locations in Southern Sweden. Rainfall deficit was calculated at daily basis as precipitation minus the actual crop evapotranspiration (ETa), ETa was calculated by multiplying reference evapotranspiration (ETo) with the crop coefficient (Kc) as proposed in Allen et al., 1998. ETo was calculated using Hargreave's method as described in Hargreaves and Samani (1985). Input data for historical and future climate data was generated by Swedish Meteorological and Hydrological Institute. Future climate data included datasets of five different global climate models and two emission projected scenarios, RCP 4.5 and RCP 8.5. Irrigation demand for winter wheat, spring cereal, forage (Alfalfa) and potato were assessed. These crops are the major crops in Sweden, having different cropping period and differ in water stress sensitivity. Root depths for winter wheat, spring cereal and forage were assumed to be 1 m and the total amount of plant available water was set to 110 mm. The root depth for potato was set to 0.45 m and plant available water to 60 mm. The water balances for each crop and season were calculated for a period of 15 days. In winter wheat, spring cereal and forage irrigation was carried out when soil moisture content decreased to 60% of the plant available water with an amount that kept the soil moisture above the threshold value. For potato irrigation was carried out when soil moisture decreased to 80% of plant available water. Irrigation demand for both historical periods had a similar pattern. However, in all three locations both periods showed a high variability between the years indicating that in some years irrigation demand was very low and in others very high. Rainfall deficit was in average for the two months in the spring (start of the seasons) around 80 mm for the three locations. For the two summer months (middle season) the average rainfall deficit ranged between 100-160 mm depending on the location. During the last two months late summer and early autumn (end of cropping seasons) the rainfall deficit was relatively small and ranged in average between 10-50 mm. The total irrigation demand during the cropping seasons ranged between 50-300 mm, in general potato and forage were in higher need of irrigation. Irrigation demand according to the projected future climate data for both RCP4.5 and RCP8.5 had a great variability, mainly because the data output from the various climate models that were included in this study but also because a high variability between years with more extreme values. In general the rainfall deficits followed a similar pattern as for historical climate but with bigger range between dry and wet years. No differences were observed between the two RCP scenarios. As a main conclusion future climate in Southern Sweden will bring some challenges for farmers since they should be able to handle periods with rain deficit of variating amplitude. This creates difficulties when designing irrigation system that will have enough capacity and from economical point of view motivate the investment, the result could be at during some years the irrigation capacity will not be sufficient and under other years will be too much. In addition, the results indicate that periods with surplus rainfall will be more frequent in the future during the cropping period. This will bring further requirements of investments in drainage system. In this study we did a number of simplification in order to handle a large number of data in the limit frame for the project. For future studies we intend to expand the analyses to other soils having different water holding characteristics. However, further studies are needed for in particular for winter wheat and spring cereals under similar conditions as in Sweden in order to define strategies for supplemental irrigation in order to irrigate during the conditions that the best return can be achieved. References Allen, R., Pereira, L., Raes, D. och Smith, M. 1998. FAO Irrigation and Drainage Paper No. 56. Crop Evapotranspiration- Guidelines for computing crop water requirements. FAO, Water Resources, Development and Management Service. Rome, Italy. Hargreaves, G.H. och Samani, Z.A., 1985. Reference Crop Evapotranspiration from Temperature. Applied Engineering in Agriculture, 1(2): 96. DOI:https://doi.org/10.13031/2013.26773

T-A-02: Irrigation & water resources management in transboundary basins AND Managing competing water demands (I)

Session Cancelled

T-B-02: Climate change and its impact on agriculture, irrigation, and drainage (III) AND Irrigation water footprint (I)

Charles Nhemachena- Review of climate change and variability impacts on water resources, irrigation and agricultural sector performance in Southern Africa - The agriculture sector remains an important sector in driving economic transformation, development and sustainable livelihoods in developing countries. For example, efforts to enhance agricultural productivity are central to the African Unions 2014 Malabo Declaration which position the sector as an engine to drive inclusive economic growth, employment creation and ending hunger and malnutrition in Africa. One of the commitment areas of the Malabo Declaration focuses on increasing the use of improved inputs such as irrigation technologies to enhance agricultural performance. However, the spatial and temporal variability in climate including current and expected changes manifesting in different forms: changes in temperature; rainfall distribution and patterns; intensity and frequency of extreme events (floods and droughts) affect water resources and irrigation potential across the region. The impacts of climate change and variability on water resources and irrigation have significant effects on the performance of the agriculture sector. Such impacts threaten progress in economic growth and development including livelihoods of millions of the regions people who rely on the agricultural sector and natural resources. Despite various research on climate change impacts on agriculture and water resources, little has been done to comprehensively review and synthesise the nexus of impacts of climate change and variability on water resources, irrigation and agricultural sector performance in Southern Africa. This paper synthesises how changes in climate and its variability impact on water resources, irrigation and the performance of the agricultural sector in Southern Africa. Measures for adapting and building resilience on water resources and irrigation for improved agricultural sector performance were also discussed. Overall, the various literature on the above issues were reviewed and integrated in the current paper and recommendations to enhance agricultural performance through efficient and better management of water and irrigation resources were provided. Approach and methods The discussions and analysis presented in this paper were based on a comprehensive review and synthesis of relevant literature. The review aimed at synthesising the nexus of impacts on climate change on water resources, irrigation, and agricultural productivity as well as measures for responding to these impacts. The published literature reviewed has not been well integrated focusing on the issues discussed in this paper particularly in Southern Africa that is already experiencing and is expected to experience further warming and drying conditions for most parts of the region. The review was complemented with the analysis of country- and regional-level investments in building resilience of farming systems (including water resources) to climate change and variability as part of the Comprehensive Africa Agriculture Development Programme (CAADP). The focus was to better understand how countries in the region are prioritising adaptation in water resources in their efforts to enhance agricultural sector performance for sustainable and inclusive livelihoods. Extreme weather events have been recurring in the region and stakeholders have been caught unaware resulting in ad-hoc intervention instead of a well-planned response mechanism. The aim is to build resilience and adaptation, and improve risk preparedness and minimise the chronic cycle of disaster-relief aid. Results and discussion The review show that climate change and variability in the region manifest in different forms: changes in climatic variables (temperature, rainfall), frequency and intensity of extreme events (droughts, floods). The evidence of changes in temperatures (historical and projected) indicate an increase in warming in Southern Africa which is expected to continue at a higher rate than increases in global mean surface temperatures across seasons. The review of changes in rainfall show that the region has been experiencing reduced amounts in most seasons for most of the central and western parts. In addition, the onset, distribution, and duration of rainfall has been substantially affected by changes in climate and variability. Furthermore, historical trends and projections of intensity and frequency of extreme climate events (such as droughts and floods) indicate that these have increased in the region with the trends expected to continue in the future. The interaction of these changes in climate and variability and other socio-economic challenges results in adverse effects on agricultural resources such as water that translate in reduced irrigation potential across many parts of the region. For example, the drying conditions that are occurring at least every three years are significantly reducing the quantity and quality of available water resources for both rainfed and irrigation agriculture with adverse impacts on productivity. On the other hand extreme rainfall and flooding events projected in eastern parts of the region result in substantial decreases in productivity. Overall, climate change and variability contributes to increasing scarcity of productive agricultural water resources and leads to overexploitation of fragile ecosystems with detrimental effects on agricultural productivity and livelihoods. The increased scarcities of agricultural water resources and reduced irrigation potential are potential sources of conflicts for access and use of these resources given their transboundary nature in Southern Africa. Adaptation measures in water resources management to enhance agricultural productivity in the face of climate change and variability promotes efficiency and sustainable use and management of these resources. Such measures contribute to efforts to transform water resource and irrigation use in the agriculture sector towards efficient and sustainable systems that can sustain growing demand for food and fibre with less water resources. Implementation of adaptation and resilience building measures on water resources and irrigation (especially at the farm-level) are critical for farmers (especially smallholder farmers) to improve and sustain agricultural productivity. For example such measures should include farmer awareness to enhance the role of adapting water and irrigation resources in addressing productivity. Affordability and accessibility of innovative adaptation measures on water resources and irrigation remains critical and these strategies should be part of broader adaptation and sustainable development efforts in the region. Overall, efforts to enhance agricultural productivity elaborated in the SADC Regional Agricultural Policy, SADC Regional Water Policy, Revised Regional Indicative Development Plan and the African Union 2014 Malabo Declaration need to emphasize investments in sustainable management and use of water resources and irrigation to achieve sustainable economic growth and livelihoods.

Jianxin Mu - Food Security in the Face of Climate Change, Population Growth, and Resources Constraints: Implications for China - As one of the most populated and rapidly growing economies of the world, China is increasingly facing water shortages and food security challenges. The population in China reached 1.3 billion (excluding Hong Kong, Macau and Taiwan) in January, 2005, accounting for 21% of the worlds total and is predicted to reach 1.47 billion by 2030 and 1.42 billion by 2050 at the medium variant scenario. Population growth increases food demand which in turn intensifies water demand. With the improvement of peoples living standard, the dietary structure improves, including the increase in meat consumption, which requires several multiples of consumptive water to meet the same daily calorie needs. Food security issues are not particularly pressing in China presently, but will heavily dominate the national political agenda in the next twelve years as the population will reach its peak by 2030. Much will depend on local production, the global political and macroeconomic landscape and China's strategic positioning in the emerging world trade alliances. Local production will become a hostage to the variable hydrologic cycle, at least in the major food producing areas such as the North China Plain and Yellow River basin. So the great challenge for the coming decades in China will be the task of increasing food production with less water, particularly in basins with limited water resources such as the Yellow River basin. Increasing productivity in agriculture will play a vital role in easing competition for scarce resources, prevention of environmental degradation and provision of food security. Boosting crop productivity by increasing water use efficiency will be the main pathway to addressing the water and food security issues. Though it has been widely recognized that climate change and population will exert sizeable impact on agricultural water use and food security in China, the assessment of relative their impact on water and food at regional scales is very limited due to difficulties in integrating climate, population, water management and food drivers. Therefore, there is a need to quantify the impact of climate change and population changes on future water availability and food production through the use of climate and population projections using a food security model. As of this, a country level food security approach was applied in this paper to analyse how much food surplus/deficit is likely in China in years 2030 and 2050 based on the population growth and irrigation area development scenarios, and to meet that level of food production, how much water will be needed and what gain in water productivities will be required? Impacts of climate change on future water demand and water productivities were analysed on the basis of likely projections of precipitation and evaporation changes, and a stochastic analysis approach was applied to assess the risks of climate change on Chinas future water and food security. Strategies on adaptation to climate change and sustainable water resources development was lastly proposed in this paper.

Cara Drury - Irrigation Certification in Saskatchewan - Land in Saskatchewan developed for irrigation requires certification under the Irrigation Act, 1996, administered by the Saskatchewan Ministry of Agriculture. The process of Irrigation Certification determines if the proposed land base is compatible with the proposed water source. Land base and water source compatibility ensure the sustainability of the project and prevent adverse impacts on neighbouring lands. Saskatchewan follows the œIrrigation Suitability Classification System for the Canadian Prairies • when assessing land for Irrigation Certification. This classification system considers several soil and landscape criteria when determining suitability. Parameters measured include soil texture, soil structure, moisture holding capacity, infiltration rates, salinity, sodicity, geologic conformity, topography, depth to water table and drainage, among others. As part of the assessment process ministry employees perform an on-site soil investigation. Soil investigations include soil samples, topography mapping and a detailed salinity survey. The detailed salinity survey of the field is conducted with an automated, geo-referenced dual dipole EM38 (EM38-DD) unit. The data collected with the EM38-DD is used to generate two salinity maps; one depicting the salinity profile for the 0-0.75m depth increment and another depicting the salinity profile for the 0-1.5m depth increment. Comparing the two profiles can provide valuable information with regards to water table depth and also the internal drainage of the soil. An overview of the Irrigation Certification process will be presented.

Margo Redelback - Alberta Irrigation Sector 2005-2015 Conservation, Efficiency and Productivity Plan and Evaluation - In addition to providing water for crops, the Alberta Irrigation Sector supplies water for livestock, rural communities, wetlands, recreational opportunities, commercial and industrial use and other purposes in accordance with its water licenses. Collectively, Alberta irrigation districts are licensed to deliver approximately 3.4 billion m3 of water. The Alberta Irrigation Projects Association (AIPA) represents all 13 irrigation districts in Alberta. In 2003, the Government of Albertas Water for Life Strategy set a target to improve efficiency and productivity of water use in Alberta by 30% from 2005 levels by 2015. One of the recommendations from the Water for Life strategy to encourage and achieve provincial water conservation and the efficiency and productivity of its use was identified as the preparation Conservation, Efficiency and Productivity plans for all Alberta water using sectors. The intent of the sector plans was to: ¢ set measurable targets and goals, ¢ guide implementation of activities to achieve conservation, efficiency and productivity, ¢ evaluate the success of the activities implemented. The Alberta Irrigation Projects Association committed to preparing a Conservation, Efficiency and Productivity Plan for the Irrigation Sector to reinforce existing ongoing efforts to improve efficiencies and conserve water. Development of the CEP plan, defined eight targets to help guide and assess progress in CEP improvements within the sector for the period 2005-2015 en-route to achieving the Water for Life goal of 30%. The primary target of the irrigation sector CEP plan is to achieve a 30% increase in combined Conservation, Efficiency and Productivity. Seven additional targets have been identified related to activities undertaken that enhance the efficiency of the Alberta irrigation system and promote water saving technologies and activities for individual agricultural producers. Collectively, the implementation of the activities identified under each target will succeed in meeting the 30% goal. Upon conclusion of the 2005 to 2015 period, the Alberta Irrigation Sector did achieve success in meeting the eight CEP sector targets and supporting the Alberta Water for Life Strategy goal of a 30% increase in combined CEP. Irrigation sector efficiency gains measured as the reduction in diversions on a 10 year running average basis equaled 26% and productivity measured using the three indicator crops of potatoes, sugar beets and soft white wheat increased by 22% over the time period. Combined improvements in efficiency and productivity within the sector totaled 48% exceeding the 30% target by 18%. The report details the eight sector targets, outlines the implementation activities undertaken that collectively conserve water, and increase efficiencies and productivity and details the achievements under each target.

T-A-03: Managing competing water demands (II)

Caren Jarmain - Remote sensing, Machine Learning and Water Accounting: New-age tools to support and age-old challenge - Water demand for irrigated agriculture has to be balanced with competing water demands for industrial and domestic use. An increasingly variable and changing climate requires innovative thinking for sustainable management of water resources. œKnowledge is power • is key in this regard. Advances in Geographical Information Systems (GIS) and Remote Sensing (RS), together with frameworks like Machine Learning (ML) and Water Accounting (WA), make near-real time crop water demand management possible within a spatial context. A recent South African (SA) study illustrated how GIS, RS and ML can be employed to (a) map the position of irrigated agricultural fields across an entire country and (b) determine the (real) monthly and seasonal crop water use for each of these agricultural fields. The actual crop water use information provides a good indicator of crop water demand, especially when extracting statistical information showing the frequency distribution (crop water use vs. frequency) thereof. This study showed the wide range in agricultural (both irrigated and rainfed) crop water use in space (in and between regions across SA) and time (over a season and year). As crop water demands are not static and variation exists over space and in time, this variability has to be taken into account for sustainable water management. This study employed the modified WA + framework to combine all the datasets generated with additional information describing the catchment water balance and to compare water availability, with crop water demands as well as water demands by the environment. The results for the selected catchments showed that some catchments are clearly over-allocated and suggest active and pro-active water demand management. It also highlighted water availability in other catchments, with the potential for further agricultural or other expansion of water use. This study showed how new-age mechanisms can be used to generate a wealth of information and be implemented operationally, to support crop water demand management.

Carl Walters - Managing competing water demands through a partnership approach in Northern Victoria, Australia - N/A

Sitti Rahma Ma'mun - Alternative institutional arrangement for sustainable irrigation: a study of local water users association in Indonesia - Irrigation has been the backbone of agriculture development in Indonesia. The long history of irrigated agriculture in Indonesia started with a small scale and very simple hydraulic system which was developed through time since the ancient Java around the 5th century. Nevertheless, despite more than a century experience of irrigated agriculture and the huge investment in irrigation development, the performance of the irrigated agriculture in public managed schemes was reported to be lower than its technical and economic potential. Some studies have been done to evaluate the effectiveness of the policy reform for improving irrigation performance and farmers participation. However, other than the Balinese subak, very rare has addressed institutional arrangement at the local level and its capacity to deal with the future challenge and fit in the broader scope of water management in Indonesia. Therefore, the purpose of this paper is to examine the effectiveness of institutional arrangement at the local level and search for ways to improve the arrangement. It is argued that an appropriate institutional arrangement will provide incentives for collective action to emerge among farmers, by which farmers participation in managing the irrigation systems can be improved. The study of institution has gained enormous attention in the last few decades. Institution emerges to reduce externalities due to individualistic human behavior that seeks to maximize utility on resource use (North 1986). This is especially true for a common pool resource (CPR), a natural or man-made resource system which is characterized by subtracability of use and costly for exclusion of some potential beneficiaries (Ostrom 1990). Without any restriction, the use of CPRs will lead to destruction and leave no benefit to individuals. To address this problem, Ostrom (1990) proposes self-governing institution, based on some case studies that reveal successful managed CPRs by local communities rather than govern by the state (public) or market (private property). Ostrom (1990) argues that individuals have the capacity to extricate themselves from the dilemma of the commons. After extensive studies of long enduring self-governing institutions, Ostrom identifies eight general regularities which she considers as underlying principles for a system to sustain over a long period of time. According to her, these principles can create an incentive for collective action in managing CPRs (Ostrom 1990). METHODOLOGY The study was conducted in Southeast Sulawesi Province, the eastern part of Indonesia. Data was collected through in-depth interviews with government officials who deal with irrigation management at provincial, district and subdistrict levels. The focus group discussions were carried out in three districts, i.e. Konawe, Konawe Selatan and Kolaka Timur. Institutional arrangement of local water user associations (WUAs) is evaluated using Ostroms Design Principles (DPs), with some modification by Cox, Arnold, and TomÃ¡s (2010). What important is not in terms of success or failure of the system under study, but how the existing arrangement can be made effective in dealing with the future uncertainties and changes in water availability and how it can fit in the broader context of water reform in Indonesia. RESULTS AND DISCUSSION Given that the characteristics of water resources and the existing infrastructures, different institutional arrangements can be found in the study area. The weak institutional arrangement of water management in Cialam Jaya compare to other villages is more likely due to its simple village irrigation system without storage and proper tertiary canals with any device to regulate the flow. No explicit collective arrangement that governs water appropriation has caused more conflict on water allocation during the dry season. While building a storage and tertiary units with regulating device could be a solution, it might be not cost effective considering the location of rice fields which is higher than the watercourse. In terms of participation in operation and maintenance (O&M), WUA in Duria Asih is better than WUAs in other villages. It is important to note that there is a significant difference in reliability of water supply between Duria Asih and Wonggeduku with relatively stable all the time on the one side, and other villages. On the contrary, the characteristics of water resources in other villages, expect of Cialam Jaya, necessitate more flexible detail water allocation mechanism during the dry season. Although the cost-benefit principle has not been fully realized by WUAs in the study area, the above result indicates that farmers are willing to pay for the irrigation service, either with labor, a combination of labor and harvest, or combination of labor, harvest, and cash, providing that they have secure access to irrigation water. The operational rule in Duria Asih that allows a farmer who cannot pay the ISF to pay with unskilled labor in designated irrigation canals under the supervision of WUA, is an alternative to increase farmers participation in the irrigation O&M. Currently, labor is the most common contribution to the O&M of an irrigation system in Indonesia, and perhaps in most of the developing countries. Nevertheless, labor contribution is mainly limited to regular maintenance such as canal cleaning before the planting season in the tertiary units, while bigger or major maintenance is handled by the government. As it is known, irrigated agriculture in Indonesia is dominated by rice farming and the majority under subsistence condition with average landholdings less than 1 ha (ADB 2016). The flexibility of ISF mode of payment will allow poor resource farmers to contribute to the irrigation system O&M. A study by Abramson et al. (2011) that shows a high willingness to work for improved water service in rural Kenya, suggest the potential of using labor as payment to recover the cost of water service. This practice had actually been implemented in the Subak system before the 70s in Bali, with detail arrangement of labor or in-kind contribution to irrigation maintenance, that also covered major maintenance (Birkelbach 1973). Thus, promoting cost recovery of the irrigation systems using this approach is feasible. Overall water allocation in the IDs under study can be said negotiated water allocation mechanism, whether it is at the basin council, the irrigation commission or the sub-district level. So far, water allocation mechanism has not clearly facilitated an equal sharing system in the irrigation districts, or between the upper stream and downstream users. This might create problems in the future when the demand for water outgrow the supply. CONCLUSION The evaluation of local institutional arrangement using Ostroms design principles is useful to explain current institutional arrangement at the local level and shows how the institutional arrangement provide a set of incentive or disincentive for individuals to involve in collective action in managing the irrigation systems. In general, the results conform with Ostroms DPs as in many studies on the irrigation system. The findings point towards the need for ˜nested enterprise design principle to facilitate an equal sharing system for all WUAs in an irrigation district and between irrigation district and other users in the river system. REFERENCES Abrams on, A, Becker, N, Garb, Y & Lazarovitch, N 2011, 'Willingness to pay, borrow and work for rural water service improvements in developing countries', Water Resources Research, vol. 47, no. 11. ADB 2016, Indonesia Country Water Assessment, Asian Development Bank, AD Bank. 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Muhammad Usman Rashid - Formulating diagnostic assessment and modernization approach for large irrigation systems - The optimized development and utilization of water resources is utmost important for acquiring the sustainable goals of development of United Nations i.e., water availability, zero hunger along with economic growth of world. Modern and efficient irrigation system facilitates to fulfil the irrigation demand and ensuring water saving and water availability. Modernization and remodelling approach for alluvial irrigation system has been developed and implemented in the manuscript on Upper Jhelum Channel (UJC) which off-takes from River Jhelum, Pakistan. The main features of the modernization approach covers structural and functional interventions focusing conveyance system and application of water in the fields. The in-depth analysis of existing structural conditions as well as application practices along with the associated problems was the first step. In next step, the remodelling and modernization frame work focusing hydraulic, structural and economic interventions was performed. Upper Jhelum canal (UJC) with parameters; 142 km length, 362.7 m3/s discharge, 244,329 culturable command area was initially designed on Mannings Approach in 1904 and commissioned in 1915. The field observations and data were collected through channel surveys and site visits. The in-depth analysis envisaged several structural deteriorations of channel widening, embayment at downstream structures, insufficient freeboard and excessive silt deposition etc. The existing bed width (B) was found 73 to 82m, whereas the depth (D) was 1.5 to 3.5m in different reaches of UJC. The B/D ratio ratio was found as high as 55:1 due to widening of channel, banks erosion and raising of bed level due to silt deposition instead of original B/D ratio of around 20:1. The operation of UJC for most of the time during its commissioning was at very less discharge which caused less water velocity and was the main reason for silt deposition. The other problems were appeared when the channel had to be operated seldom at its design discharge for which the channel did not had capacity due raising of bed level. The remodelling was suggested for enhanced discharge of 420.51 m/s envisaged on the basis of crop water requirements analysis of the area, water availability and with the consent of provincial irrigation department. The hydraulic modelling for UJC was carried out on the basis of different design approaches suitable for the channel i.e. Lacey, Mannings and Tractive force approaches. Sensitivity analysis was carried out for UJC to optimize the width, depth and other design parameters hydraulically and economically. Laceys regime method is most extensively used method for hydraulic design of alluvial irrigation channels in Pakistan and India. Performance of the channels designed with Laceys parameters depicts regime canals even after several decades of commissioning. The design parameters were computed by different design approaches and by allowing minimum deviation in existing existing parameters. Laceys design parameters were recommended for remodelling of UJC. The width and depth was found to 73.2m and 4.1m for reach 8.4-74.4 km of 420.8 m/s discharge. However, the width and depth of reach 74.4-127.4km was found 70.1m and 2.9m. The optimized design brought B/D ratio within permissible limits and also focused to avoid excess structural modifications to keep the remodelling and modernization cost economical. The hydraulic analysis of bridges depicted that the structures were safe to pass the enhanced discharge. However, the freeboard of some bridges was found deficient for which raising of deck slab was proposed. The scour depth was found 1.2 m below the channel bed. The foundations of hydraulic structures were also found safe as were placed lower than the scour depth. The existing conveyance efficiency of UJC system was found to be around 40-45% which was in line with most of the irrigation systems of Pakistan and therefore, needed to be enhanced. The major losses were associated with inefficient water application surface irrigation methods i.e. basin, furrow and border. The conveyance efficiency of primary channel was found high followed by secondary and then tertiary irrigation channels. The UJC conveyance system visited and observed that some channels of secondary system was already concrete lined, however the tertiary conveyance channels were found 33% lined in the head reaches. It had been proposed to lined the secondary and tertiary channels of UJC system in steps to make it practically feasible due to limited resources giving priority to deteriorated channels and reaches to enhance the conveyance efficiency. It is well established that the pressurized water application systems i.e. drip and sprinkler which have high efficiency. The main reasons found for continuation of surface irrigation methods are lack of awareness of farmers to pressurized irrigation system, unavailability of enough funds, non availability of pressurized system equipment in local market, high electricity cost, ongoing energy crisis and limited support from the state. The comparison of land and water productivity of different developed countries of the world and region indicated that Pakistans productivities were low. Some efforts have been made to introduce pressurized irrigation systems in the country but without any sustainable success. A recent project being undertaken by the Agriculture Department, Punjab in the nearby area (48563 hectares) of UJC for installing high efficient irrigation water distribution systems are being installed on 40 percent cost sharing by the beneficiaries and 60 percent by the project funded by the World Bank. Cost of drip irrigation systems installed under this project ranges from 2,380 to 4,441 US $ per hectare. Average cost per hectare for orchards was US$. 2,567 and for vegetables it was US$. 3,479. Similar sustainable project with public-state partnership was recommended for judicious implementation in UJC system to fulfil the current and future demands. The irrigation water productivity can be enhanced by optimizing the cropping pattern by growing more high value and high yielding crops considering the land suitability. Key crops identified in the area were wheat and orchards for Rabi (October-March) season and rice, cotton and orchards for Kharif (April to September) season. In-addition citrus fruit ˜orange of the area has huge demand and is liked all over the world due to its unique taste is recommended to enhance its production. The cropping intensity of these high value orchards and crops may be increased so as to make the cropping pattern optimized. Therefore, to meet the food and fibre requirements, the modernization of UJC conveyance system, adoption of pressurized irrigation system and growing high value crops is the way forward.

T-B-03: Irrigation water footprint (II)

Jiabin Wu - Quantification of alfalfa water uptake from different layers and root zones under drip irrigation using stable hydrogen - How to quantify the root water uptake from different soil layer under drip irrigation condition accurately, is still a great challenge. In this study, the stable hydrogen and oxygen (Î´D and Î´18O) isotopes of soil water, stem water, irrigation water in the alfalfa field system under drip irrigation condition were measured during 2016-2017. The variation rule of stable hydrogen and oxygen isotopes reflect the characteristics of water circulation in the field. Compared with the traditional method, the œfingerprint • tracer effect of stable hydrogen and oxygen isotope analysis technique can better reflect the characteristics and laws of the movement of water in the root layer of crops. The root water uptake was estimated by the multi-source mass balance method (IsoSource model). As a perennial herbage, alfalfa whole growth period can be divided into growth period and hibernation period. In the experiment, the irrigation of the whole growth period of alfalfa is divided into the growth period irrigation (Abbreviated as GPI , the experiment took place in second branching period of alfalfa in August 2016), the frozen water irrigation (Abbreviated as FWI, the experiment took place in October 2016, it is about to enter the hibernation after the harvest of alfalfa), and the thawing water irrigation (Abbreviated as TWI, the experiment occurred in May 2017 when alfalfa returning to green period) according to its growth characteristics. GPI provides good water supply for the evapotranspiration of alfalfa growth, FWI and TWI ensures a good water condition during winter, thus promoting the safe overwintering of alfalfa. Results showed that before and after GPI, 10cm-40cm soil water is always a stable source of water in alfalfa. The probability of the soil water with 30cm depth as the main source of water is higher before GPI, and the contribution rate of 15cm, 30cm and 40cm depth is higher after GPI. This is probably because the 10cm-40cm depth roots of the 3 years old alfalfa grow well, and the water uptake is relatively large. Alfalfa did not absorb water from FWI, although the green rate of alfalfa in the following year increased with the increase of water quantity of FWI. The reason is that the moisture content of FWI is not directly utilized by alfalfa after mowing. However, FWI increase soil moisture and reduced the temperature variation range of root zone before winter, at the same time the soil after FWI could be loosened by freezing and thawing. So FWI provides better habitat conditions for alfalfa to survive winter safely. In the experiments, the irrigation amount of TWI is designed to be low (L), medium (M) and high (H), and the irrigation ceiling corresponded to 50%, 70% and 90% of field water capacity of alfalfa root layer respectively. Alfalfa began to absorb soil water third days after TWI in turning green period, and the main water absorption layer deepens with the increase of the amount of irrigation. On the fifth day after TWI, soil water contribution rate was more uniform at different depths, this may be related to the migration characteristics of the wetting front. The yield of alfalfa increased more than 22% through FWI and TWI, the reason is that FWI and TWI have increased the survival of alfalfa, and they are directly related to the density and quantity of alfalfa harvested at last. This indicates that FWI and TWI can effectively alleviate the freezing and drought stress during hibernation period.

Amali Abraham Amali - Assessment of crop water use and stress using multidate satellite data - Detection of water stress can help farmers in taking proper measure for reducing negative impacts on productivity. Water stress can be detected using Ground based techniques and remote sensing based techniques. All ground based measurement can be used successfully for measuring plant water stress at ground level or local regional level, but they are not applicable for large spatial scale like remote sensing does. Either ground measurement can be used for ground truthing of remote sensing applications.Remote sensing derived information is used to evaluate spatial and temporal variations in crop growth, crop stress and supports for decision making for agricultural development.The spectral characteristic of vegetation is governed by absorption and scattering characteristic of leaf internal structure and constituents like water, nitrogen, cellulose and lignin. Cellular structure and water content of leaves are detected in near infrared and mid infrared region of wavelength, whereas, leaf pigments are detected by visible band.Land surface phenology is distinct from the traditional definition of phenology, which is the study of the times of recurring natural phenomena, i.e., the date of emergence of leaves and flowers, and the date of leaf colouring and fall in deciduous trees. TIMESAT program to develop a phenology retrieval algorithm.Vegetation water stress index (VWSI) uses NIR and SWIR reflectance band to form trapezoid to create minimal and maximal waterlines for slope and intercept which is crop specific. Land surface wetness index (LSWI) is a measure of interaction of liquid molecules in a plant canopy, that is why it is sensitive to the total liquid in crop. The index derived from SWIR and NIR has different nomenclature for different author (Gao,1996) and (Chen et al., 2005) called it as NDWI(Normalized Difference Water Index). Half-an hourly observations from an Indian geostationary satellite sensor, INSAT 3D, were used to provide minimum ground brightness (surrogate of surface albedo) from previous 30 days, cloud top albedo, brightness temperatures, atmospheric water vapour as inputs to these models in addition to global eight-day aerosol optical depth at 550 nm and columnar ozone.A PET (ET ref) product from MOSADC and Pennmen Monteith obtained using basal crop coefficient. Derived ETactual and ETref were used for calculating water stress factor (Ws) which was further used for validation. Equation for calculating water stress factor (Ws).

Haili Wang - Study on Water Demand and Suitable Soil Water Content of Banana, Guangdong , China - Bananas like to grow in hot and humid areas. Guangdong is the main producing area of bananas in China, and Gaozhou City is one of the large areas where bananas are distributed in Guangdong. And Gaozhou City is also a region where there is seasonal water shortage and less rainfall in Guangdong. Studying the water demand of bananas in this area and exploring water demand low of bananas can effectively increase banana production and save water for agriculture. This provides a scientific basis for local governments to rationally use water resources and guide agricultural water-saving irrigation, which has important practical significance. For this reason, from 1983 to 2004, the water requirement irrigation experiment for bananas was carried out at Gaozhou Experimental Station in Guangdong. Based on the experimental data, the indicators such as the water demand of banana and the changing law of water demand were analyzed, and the suitable soil moisture content of banana was proposed. Experimental studies have shown that 1) the average growing period of spring planted bananas is 358d, the water requirement for the whole period is between 802.9mm and 1733.5mm, the average for many years is 1199.3mm; and the average growing period of summer planted banana is 407d, the water demand for the whole period is between 1297.0mm and 1398.2mm with an average of 1331.1mm; 2) the water demand is relatively large from May to October, and it is smaller from January to April; 3) the average annual water productivity of spring planted bananas is 3.0 kg/m3, and the average annual water productivity of summer planted banana is 2.46 kg/m3,the spring planted bananas are more water-saving;4) the average annual irrigation frequency is 7.6 times, and the average amount of each irrigation is 50.3mm, irrigation time is mainly in the winter and spring seasons; and 5) the suitable soil moisture content during the banana growth period is 65% to 90% of the field water holding capacity.

Pilar Gil - Strategies for reducing water consumption in vineyard grapevines without affecting water status, yield and wine quality. - Wine grape (Vitis vinifera L.) is one of the horticultural crops in Chile with high economic importance. The central region of Chile has an optimal climate for producing high-quality wines because of the excellent quality obtained in the different grapevines varieties. However, in this production area, rainfall has become increasingly scarcer, affecting surface and ground water availability and thus resulting in more frequent and longer periods of water stress. Drought has threatened the water security of the area making difficult to establish new vineyard, but also less water availability has affected vine vigor, fruit yield and quality when plants demands water have not been met. Thus, water is now the main limiting factor for the production of wine grapes. Regulated deficit irrigation (RDI) in grapes has been commonly used in vineyards for enhancing wine quality, however water shortage can severely affect vineyard yield, general status and longevity. In this work we present preliminar results from a research were we evaluated the effects of irrigation water savings combined with different strategies for reducing water stress in ˜Merlot, ˜CarmÃ©nÃ¨re and ˜Cabernet Sauvignon vines. In ˜CarmÃ©nÃ¨re, plants were subjected to the following treatments: T0) Control, with conventional irrigation regimes used by local growers; T1) Water shortage equivalent to 50% of T0; T2) Partial Root Drying (PRD) irrigation resulting in a 50% reduction in irrigation volume compared to the control. In ˜Merlot, plants were subjected to the following treatments: T0) Control, with conventional irrigation regimes used by local growers; T1) Water shortage equivalent to 50% of T0; T2) Partial Root Drying (PRD) irrigation resulting in a 50% reduction in irrigation volume compared to the control; T3) Water shortage equivalent to 50% of T0 applied with subsurface drip irrigation. In ˜Cabernet Sauvignon plants were subjected to the following treatments: T0) Control, with conventional irrigation regimes used by local growers; T1) Water shortage equivalent to 75% of T0; T2) Water shortage equivalent to 75% of T0 apply with drippers under a double color plastic mulch (white color on top and black face on inside); and T3) Water shortage equivalent to 75% of T0 apply with nano-irrigation drippers. Among the measured parameters, we evaluated plants water status variables (stomatal conductance, stem water potential, relative water content), yield (yield per plant, average berry weight), and wine quality (pH, acidity, alcohol content, polyphenols content, color). As results, in general water shortage without mitigation strategy affected some waters status variables, as well as yield. In contrast, strategies such us PRD, buried irrigation and nano-irrigation did not negatively affect water status, yield and wine quality but permitted to save significant amount of water during the season.

Christopher Neale - Application of remote sensing to evaluate the spatial-temporal variation in irrigation performance in Central Nebraska, USA - This paper focus on the application of remote sensing to evaluate the spatial-temporal variation of the performance of irrigated corn fields in three Natural Resources Districts (Central Platte, Lower Niobrara and Tri-Basin) across central Nebraska, USA. Irrigation plays a vital role in Nebraskas agriculture, where in 2017, 65% of the maize and 55% of the soybeans production comes from irrigated agriculture. With an irrigated area of 3.4 million hectares, Nebraska ranks the first in the nation in terms of total irrigated crop area. Between 1959 and 2012, Nebraskas irrigated area has quadrupled from 0.8 to 3.4 million hectare. Recent droughts combined with observed Ogallala aquifer drawdown has increased pressure on the states agricultural sector to reduce its water use and improve its water productivity. The main objective of this paper is, therefore, to evaluate the irrigation performance and water productivity of irrigated cornfields under different soils with surface and center pivot irrigation systems. Data on corn yield and field level irrigation application were collected from more than 2000 irrigated cornfields over the cropping seasons of 2004 to 2012. Basal crop coefficients and biomass production have been determined using the soil-adjusted vegetation index (SAVI) obtained from Landsat satellite imagery. Reference evapotranspiration was estimated using the Penman-Monteith equation. The daily actual evapotranspiration and net irrigation water requirements were estimated by soil water balance modeling, combining the basal crop coefficient derived from the remote sensing data with soil properties, daily precipitation and reference evapotranspiration. The modeled irrigation water requirements were compared with actual and reported irrigation application data to evaluate the performance of the irrigated fields. In general, the average irrigation application depth from all farmers fields was significantly ($p<0.001$) larger than the modeled irrigation requirements. Fields with surface irrigation systems had larger application depths due to inherent characteristics of these systems. Averaged over 2004-2014 and fields, the application depths under surface irrigation systems were 9.3 times larger than the center pivot systems. The water productivity (WP), calculated as the ratio of yield to seasonal water supply, shows significant variation ($p<0.001$) between irrigation system type and among the three NRDs. The WP averaged over 2004-2012 and the fields in the three NRDs varied between 0.28 and 2.52 kg m-3, with an average of 1.14 kg m-3. On average, fields under pivot system have 13.5% larger WP compared to fields under surface irrigation systems. The average WP in Tri-Basin NRD is 15.6% and 7.7% larger than the WP in Central Platte and Lower Niobrara. One of the reasons for a larger WP in the Tri-Basin NRD is lower irrigation application frequency due to soils with higher water holding capacity. In addition, the average yield in Tri-Basin was relatively larger than in the other two NRDs

T-A-04: Managing competing water demands (III)

Leila Eamen - An Evaluation of Current and Future Water Allocation Strategies in the Saskatchewan River Basin, Canada - Overexploitation of water resources and degrading their quality by Human-driven activities has reduced the amount of available water in many regions. Population growth and their increasing demand intensify the competition among users for more water. Under such circumstances, allocating the scarce water resources in an efficient manner among the competing users becomes more controversial. This challenge is more critical in multi-jurisdictional basins like the Saskatchewan River Basin (SaskRB). Hence, a proper understanding of the impacts of existing and future water allocation strategies can help to allocate the limited water resources more efficiently. In the SaskRB, water has been allocated through the licenses that are mostly issued on a œfirst in time, first in right basis. In this study, we focus on Alberta and Saskatchewan as the two main provinces that share the Saskatchewan River Basin. Upstream Alberta is facing a challenge of water over-allocation due to extensive agricultural and industrial developments. Meanwhile, downstream Saskatchewan has not yet used the total amount of water it has claimed and is entitled to. Thus, the Saskatchewan province is planning for new developments that demand more water from the South Saskatchewan River. Therefore, in this presentation, we aim to evaluate the existing water allocation system and assess the economic impacts of alternative water allocation strategies in the Saskatchewan River Basin. Within this context, first, we analyze water allocation and actual withdrawal data in different sectors for period 2005 to 2016 in the SaskRB to examine the current status of water use in the basin. A GIS data-frame is also developed by employing the ArcGIS platform to study the spatial distribution of different water users in sub-basins of the SaskRB. Second, we employ an Input-Output hydro-economic model to study the economic impacts of the existing and alternative future water allocation strategies on the economy of the SaskRB. The Input-Output model is an analytical framework developed based on the Leontief Input-Output model and the Canadian Input-Output tables for year 2014. This model uses inter-industry relationships in each province to estimate the changes caused by different water allocations. We couple this model with a water resources system model already developed within the MODSIM-DSS framework for the SaskRB that provides us with alternative future water allocation scenarios. Our results show that during the study period, total annual water withdrawals from the surface water resources in Alberta and Saskatchewan did not exceed 51 and 30 percent of the allocated amount through the licenses, respectively. Results also demonstrate that the amount of agricultural water withdrawal from the surface water resources in Alberta and Saskatchewan provinces had more fluctuations (as expected), compared with the other sectors. Moreover, this study reveals that in some of the sub-basins, the ratio of water withdrawals to the entitled water has changed considerably over time. With the existing water allocation strategy, agriculture is the third and 17th biggest contributor to the provincial gross domestic product in Saskatchewan and Alberta provinces, respectively. We evaluate and report how the economy of the region might change under different future water allocation scenarios.

Mohammad Ghoreishi - Improving Resilience of Water Resources Systems through Public Awareness: The Key Role of Media in Affecting Agricultural Water Use - In todays world, media plays a crucial role in shaping public opinions and changing public beliefs. There are examples in the literature that indicate a decrease in water use in response to widespread media coverage about droughts, and also adaptive behaviors in response to flood media coverage. Socio-hydrological models can be used to simulate the coupled human-hydrology systems and evaluate how much public awareness can affect human responses to environmental events, such as droughts. To cope with droughts, water policies in many areas have shifted to decreasing water demands using decentralized solutions such as water efficiency improvements, thereby improving water resource resilience and reducing human vulnerability during drought years. However, the important role of media in changing water use, and therefore in improving water resource resilience, has often been overlooked in socio-hydrological models. This is complicated because the quantification of such media coverage and the relationship with human behavior is non-trivial. In this work, we address this challenge and conduct empirical analysis to understand and quantify this role in the South Saskatchewan River Basin, located in Western Canada. This basin has been threatened by drought several times in the last two centuries, leading to widespread socio-economic damages. These unprecedented socio-economic impacts resulted in adaptive responses from farmers in Saskatchewan River Basin, including water conservation, water sharing, drilling new wells and water transfers. In this study, we use news media coverage as an index to quantify public awareness, which can be further incorporated in socio-hydrological models. After quantifying the media coverage in Canada using an open-source software called Articulate, we assess the relationship between agricultural water use and public awareness. The results highlight the key role of public awareness through media in agricultural water use, which can help planners to make effective policies for raising public awareness to drought through public engagements and education.

Andrew Slaughter - Water resources management modelling for achieving equitable sharing of water within the Saskatchewan River Basin - Although Canada is generally regarded as being fairly water secure, water availability in Canada is subject to a high degree of temporal and spatial variability. This variability is likely to be exacerbated in the future by an increased frequency of droughts due to climate change. Canada is also experiencing expanding development, and some of Canadas river basins have come under increasing pressure due to human-related water demand. Integrated Water Resources Management (IWRM) promotes inclusive and coordinated management of water and seeks to achieve equitable and sustainable water sharing. Achieving equitable sharing among competing demands for water within large and complex basins requires trade-offs, investigation of management scenarios and stakeholder negotiation. Water resources management models are essential tools within this process, and the Integrated Modelling Program for Prediction and Management of Change in Canadas Major River Basins (IMPC) aims to deliver decision-making tools and solutions for achieving IWRM within Canadas major river basins, including water resources management models. This study will focus on the Saskatchewan River Basin (SaskRB; ~400,000 km2) transcending the three Canadian Provinces of Alberta, Saskatchewan and Manitoba as well as a portion of the State of Montana in the United States. Portions of the SaskRB have already come under water stress, for example, the Bow, Oldman and Red Deer rivers within southern Alberta. The management of water within the SaskRB is currently administered according to provincial boundaries, with the water within the Alberta, Saskatchewan and Manitoba portions of the SaskRB managed separately, with limited cooperation and data sharing between the provinces. Sharing of water within the SaskRB between the provinces has been achieved through the Master Agreement in Apportionment (1969), and it is likely that this relatively simplistic arrangement will be inadequate to achieve equitable sharing between the provinces and water users in the future, given the anticipated increased hydrological variability and water demands in the basin. The aim of this study is to investigate whether equitable sharing of water can be achieved in the SaskRB under future scenarios. The SaskRB water management operating policies for each of the provinces will be consolidated within one water management model encompassing the entire SaskRB. The Water Resources Integrated Modelling System 2 (WRIMS2) will be used, as a preliminary investigation of WRIMS2 indicates that the model has sufficient flexibility to represent the complex operating policy of the SaskRB. WRIMS2 will be used to investigate the delivery of water among competing water demands across the entire SaskRB in an integrated manner. Water delivery to different categories of users under water stress will be investigated. In particular, the effects of delivery of environmental flows on other demands within the basin will be investigated. The study will discuss the possible implications of achieving equitable sharing of water in the SaskRB for different water users, particularly under drought conditions.

Khaled Akhtar - Bow River Sim – A Serious Game for Communicating Bow River Integrated Water Management - Serious Gaming is a broad term used to describe a wide variety of interactive digital products, from flight simulators to city management games. The central philosophy of serious gaming is that it brings together elements of simulations (a real-life situation, event or activity is imitated) and games (players, rules, competition, co-operation). The majority of serious games synthesize aspects of simulation and traditional gameplay to deliver an experience with a particular end goal for the user. Emerging water resources management challenges for complex large basins prompted Alberta Environment and Parks (AEP) to develop Water Resources Management Model

(WRMM) to efficiently allocate finite water resources among competing demands in the Bow River watershed, in the most efficient way by incorporating the water allocation rules of the Alberta Water Act legislation. However, the model is not designed as an interactive and educational tool. Recently AEP came up with a modern, smart and holistic approach to practice the Integrated Water Resource Management (IWRM) through the serious gaming platform without losing focus on stakeholder participation. BGC Engineering Inc. partnered with the Centre for Digital Media is retained by the AEP to develop a serious gaming prototype, Bow River Sim. The Game aims to make sustainably-based decisions that maximize social, economic and environmental benefits while managing a finite water supply. The Game incorporates the principles of ˜Meaningful Play and provides an easy-to-navigate user interface, a colorful character named ˜Wheaton, fun gameplay and visuals. Tutorials and water management challenges help guide the learning process for the users. This presentation will provide an overview of the Bow River Sim and demonstrate how innovations such as serious gaming can promote dialog and discussion among stakeholders.

Clarke Ballard - Competition for irrigation water - Case studies - Worldwide there is increasing competition for water already used for irrigation. Reasons include: * development of new irrigation projects; * movement of water to urban and industrial use; * increasing recognition of environmental needs to maintain river health; * decrease in total resource because of climate change. The WG on Managing Water Scarcity under Conflicting Demands has asked its members to provide case studies from their countries setting out: * reason for the competition; * strategies used to accommodate the competing demands; * the success or otherwise of the strategies. The paper will summarise the case studies received and draw out both common elements and differences in approach to the problem.

T-B-04: Drainage and flood control strategies (I)

Heidi Salo - Assessing the difference between trencher and trenchless subsurface drainage methods through groundwater level observations - Subsurface drainage in Finland is mostly implemented with trencher or trenchless method. The main difference between the methods is that in the trencher method the drain trench is excavated and backfilled after placing the drain pipe at the bottom of the trench, while in the trenchless method soil is lifted up and the drain pipe is placed in the drain depth without soil excavation. This study focused on investigating the differences in the drainage performance between these methods in a field in northern European climate conditions. The aim was to quantify differences between the methods using groundwater level observations and statistical analysis. The groundwater level data was gathered from an experimental field in middle-Finland. The field was divided into eight sections: Four sections were drained by trencher and four by trenchless method in May 2015. The depth of the drainage was 1.0 m and the drain spacing was 15 m. Groundwater level was measured manually from each field section at four different distances from the drain line over a period of two years (4.6.2015"30.6.2017). Measurements were gathered approximately twice a week during March"November and once a week during winter. In addition, groundwater level was automatically recorded from one trencher and one trenchless method field sections. The data from the automatic measurements was used for validating the manual observations. The manual data were used for testing the differences in groundwater level between the trencher and the trenchless method sections as well as the differences between the same drainage method sections (trencher-trencher or trenchless-trenchless). The results showed that the groundwater level was in average 0.1"0.15 m higher in the trenchless sections, where 60"90% of the groundwater level observations were above the levels in the trencher sections. Statistical differences were found between the same method sections, while the main differences were found between the trencher and the trenchless method sections (Sens slope, mean absolute deviation). The mean deviation between the minimum and maximum groundwater level showed more variation within the trenchless sections (0.41 m) than the trencher sections (0.38 m). The field sections were tested only in terms of the drainage method, while soil type and topography seemed to have a contribution to the differences within the same method sections. The overall differences are not likely to affect cultivation activities, even though occasional larger differences in the groundwater level (> 0.4 m) were recorded.

Olle Häggblom - Impacts of supplementary drainage on the water balance of a poorly drained clayey agricultural field - In Northern Europe, field cultivation is challenged by long winters, spring snowmelt and heavy autumn rains. Efficiently functioning drainage secures soil trafficability and maintains suitable moisture conditions in the root zone for cultivation activities. In Finland, subsurface drains are the standard method of draining agricultural fields, and the majority of the fields were mainly subdrained during the latter half of the 20th century. Presently the old drainage systems create an increasing need for improved drainage practices. Improved drainage practices can have major impacts on the fluxes of water and environmental loads. To predict the hydrological impacts of the improvements, it would be essential to holistically understand their impacts on water balances of the fields. The objective of this study was to quantify the impact of supplementary drainage on field water balance during a nine year period using data from a clayey field and hydrological modelling. The study site is a field section (3.4 ha) located in Southwestern Finland. Drain discharge, tillage layer runoff and ground water level have been monitored at the study site since 2007. The field was originally subsurface drained in the 1950s with a drain spacing of 32 m and a depth of 1.0 m. In spring 2014, two supplementary drains were installed between the original drains, decreasing the drain spacing to 10.7 m. To holistically quantify the hydrological impacts of the improved drainage, the hydrology of the field section was simulated with the FLUSH-model, which is tailored for simulating water flow in drained structured clay soils with preferential flow pathways. The model is based on dual-permeability approach, where the soil porosity is divided into mobile soil matrix and macropore systems. Two 2D model applications were created to describe (1) the original drainage, and (2) the supplementary drainage. The model parametrizations were calibrated and validated against hourly drain discharge and tillage layer runoff measurements, and bi-weekly groundwater level observations. To study the hydrological impacts of the supplementary drainage installation, the period June 1, 2008“May 31, 2017 was simulated with both model parametrizations. FLUSH was able to reproduce the measured long-term quantities of drain discharge and tillage layer runoff in the original and the supplementary drainage applications in terms of the annual mass deviance between simulations and measurements (-7 % for the original drainage and -11 % for the supplementary drainage). Also the simulated ground water levels correlated with the observed levels in terms of the mean absolute errors (0.35 m for both model parametrizations). The simulated drainage scenarios showed that the supplementary drainage mainly affected the subdivision of total runoff into the outflow components, including drain discharge, tillage layer runoff and groundwater outflow. The supplementary drainage increased the drain discharge by 260 %, while the tillage layer runoff and groundwater outflow decreased by 54 % and 16 %, respectively. The impacts of improved drainage on groundwater outflow in clayey fields has not been quantified in previous studies. The simulated evapotranspiration was not affected by the supplementary drainage. There was a 5 day time difference between the scenarios in reaching the groundwater water depth of 0.6 m, which was estimated to be a desired depth for soil trafficability and root zone moisture conditions.

Helena Aijo Äijö - The effect of supplementary subsurface drainage on nutrient and sediment loading in clay soil - In Finland about 85% of the arable land needs drainage. In the southern and the south-western parts of the country 75% of the arable land has subsurface drainage. Most of the subsurface drainage has been installed 40-50 years ago. At present there is a need to improve the old drainage systems by installing totally new drainage systems or by doing supplementary drainage which means installing new pipes between the old ones. Drain spacing varies nowadays mostly between 8 and 24 meters depending on the soil type. About 10% of the arable land in Finland is clay soil. This study focused on investigating how supplementary subsurface drainage affects groundwater table depth, discharge, nutrient and sediment loading in a clay soil field in northern European climate conditions. The study has been carried out at the experimental site in Jokioinen, in south-western Finland. The soil is heavy clay and the mean slope is 1%. The field was originally subsurface drained in the 1950s with a depth of 1.0 m and gravel was used as envelope material. The field was divided in tree sections. Two of them were originally drained with 16 m and one with 32 m drain spacing. Supplementary drains where installed between the original drains in 2008 in one section with 16 m drain spacing decreasing the drain spacing to 8 m and in 2014 in another section the drain spacing was decrease from 32 m to 10.7 m. Drain flow, tillage layer runoff, concentrations of nutrients and suspended solids from the different field sections and depth of the groundwater table have been measured since 2007. The results showed that decrease in groundwater level following snow melt and rainfall events was more rapid after the supplementary drainage than before. Supplementary drainage increased drain outflow and also nutrient loads from the drains. The results suggest that supplementary drainage did not affect the nutrient concentrations, apart from the peak in total nitrogen concentration in the first 1-2 years after additional drainage.

Christopher Gallahger - Integrating Taber Irrigation District into Our Watershed: More than Mitigation - Taber Irrigation District (TID) water users demanded management not just for efficient and timely delivery, but for good water quality. Irrigators need to assure food processors of meeting irrigation use standards, and also keep increasingly high precision irrigation equipment operating on growing farms. Upon developing our most recent Strategic Plan, TID is working toward our goal of providing the best possible water quality with an extensive water quality monitoring program to understand influences, a mitigation program to control point and non-point contamination sources, and a structures program to screen/filter aquatic weeds and algae prior to delivery. Recognizing that irrigated agriculture in our district both influences and is influenced by water quality led to a change in philosophy. TID worked with our local Water Planning and Advisory Council (Oldman Watershed Council - OWC), and other agency partners to develop the Integrated Watershed Management in TID project. This coordinated approach led to Alberta Watershed Resiliency and Restoration Program funding toward a comprehensive planning document, a constructed wetland, and riparian enhancement around our three reservoirs. This initiative grew to design and installation of a tile drain denitrification system, development of a rain garden in our yard, enhanced naturalization of a drain channel, a drain water characterization study and subsequent direction on conditions for issuing drainage consents, and large-scale gabion fence screening systems with integrated settling ponds. The presentation will provide background on how TID came to adopt integrated watershed management as a water stewardship philosophy and provide details and many photos showcasing the solutions that were implemented to address drainage and storm water in our district. As a bonus the presentation will include photos and brief description of TID's coordination and response to the 2018 State of Local Emergency - Overland Flooding, declared within the Municipal District of Taber.

Wednesday, 15 August

Session	Presenter(s)	Title
W-A-01: Drainage and flood control strategies (II)	Dr Bart Schultz Robert Halliday Ryan Husband Kelly Farden	Sustainable development of the lowlands of the Netherlands in the Cultural context (Solicited) N/A Saskatchewan Irrigation Infrastructure Management System Sub-surface tile drainage project at the Canada-Saskatchewan Irrigation Diversification Centre
W-B-01: Climate smart agriculture and innovative technologies for enhancing water use efficiency (I)	Jay Bauer Maik Wolleben Edwin Kanda Kazumi Yamaoka	Utilizing Plant Response Indices for Delineating Intra-field Irrigation Management Zones Microwave Soil Moisture Sensing from Pivot Irrigation Systems Simulation of soil water dynamics under Moistube irrigation Tropical Perennial Rice farming systems (SALIBU technology) for the 2nd Green Revolution against climate change
W-A-02: Irrigation, drainage, and flood control for resilient agriculture (I)	Vijay Labhsetwar Seija Virtanen Abraham Joel for Olive Tuyishime Jason Drury Maher Salman	Irrigation and Drainage for Global Food Security Effect of controlled drainage and sub-irrigation on groundwater level, drain discharge, nutrient loadings and yields Controlled drainage for reducing nitrogen losses and salt concentrations in a clay soil under rice production in Rwanda Irrigation in Saskatchewan Solar powered irrigation for sustainable agricultural development AND Harvesting water to grow resilient agro-ecosystems and livelihoods in the face of climate change
W-B-02: Climate smart agriculture and innovative technologies for enhancing water use efficiency (II)	Dale Tomasiewicz John Hornbuckle Jarett Powers	Micronutrient Requirements of Irrigated Crops in Saskatchewan, Canada IrriSAT - An Australian experience in the development and use of innovative technology for enhancing water use efficiency In-situ Monitoring and Application of Passive Microwave Sensors for Variable Rate Irrigation Systems
W-A-03: Irrigation, drainage, and flood control for resilient agriculture (I) AND Irrigation infrastructure development (I)	Bruce Jones Kwang-Sik Yoon Pheerawat Plangoen Hafiz Faizan S. Mehdy Hashemy Shahdany	China's Irrigation, Drainage, and Flood Control Legacy Evaluation of Resilient Water Supply Alternatives for a Large Irrigation Reservoir According to the Drought Scenarios The Development of Concrete Lined Ditches Mix with Rubber Latex for Farm Irrigation System Best Management Practice for a Solar-Powered Center Pivot Irrigation System Improving Water Delivery within Main Irrigation Canals in Arid Regions Using In-Line Reservoirs
W-B-03: Climate smart agriculture and innovative technologies for enhancing water use efficiency (III)	Caren Jarmain Allan Peake Graziano Ghinassi	Supporting farmers with satellite information increases their resilience and saves water: The FruitLook story Customizing irrigation strategy to soil type and climate using the APSIM crop model Sustainable Technology to Reduce Energy Use in Travelling Sprinkler Irrigation
W-A-04: Irrigation infrastructure development (II)	Yasser Ali Sam Schaefer Mona Liza Delos Reyes Kazem Shahverdi Mykhailo Romashchenko	Egypt's experience in biological weed control by grass carp, *Centopharyngodon idella* Facility Improvements to Increase Conveyance and Recharge Capacity as a Regional Adaptive Strategy in Poso Creek Integrated Regional Water Management Plan Area, Kern County, CA Emerging design considerations for modernisation of national irrigation systems in the Philippines Fuzzy Sarsa Learning (FSL) algorithm convergence and generalization in small and large space problmes for water delivery in irrigation canals Strategy of irrigation and drainage rehabilitation and development in Ukraine up to 2030
W-B-04: Climate smart agriculture and innovative technologies for enhancing water use efficiency (IV)	Dr Susan O'Shaugnessy Dr Ragab Ragab Dr Willemijn Appels Dr Ingrid Wesström	Variable Rate Irrigation Systems with Sensor-feedback (Solicited) New technologies for more accurate estimation of crop water requirement without the crop coefficient Kc (Solicited) Exploring management of subsurface drip irrigation technology in southern Alberta: indoor insights and field findings Can you increase the crop yield with just a few irrigation events?

W-A-01: Drainage and flood control strategies (II)

Dr Bart Schultz - Sustainable development of the lowlands of the Netherlands in the Cultural context (Solicited) - This paper presents sustainable development of the lowlands of the Netherlands in the cultural context. About thousands years ago the lowlands of the Netherlands, a tiny country bordering the North Sea, consisted just of a strip of dunes along the coast, with swamps and peatlands in the deltas of the rivers Rhine, Meuse and Scheldt. Our ancestors lived on artificial mounts to be to a certain extent protected against flooding. By that time they started to dig small drains to discharge excess water. Among others this induced a subsidence process that in many parts of the country is still on-going. Due to the drainage measures over the centuries the land has subsided by in total about 5 metres and the sea level has risen by about one metre. The deepest spots in the country are now 6.5 metres below mean sea level. Because of this the low flood prone part of the Netherlands consists of polders where the water is being controlled artificially. Nowadays two third of the country is flood prone and has to be protected against flooding from the sea or the rivers. The excess rainwater has to be discharged by drainage systems and all this water has to be pumped out by drainage pumping stations. Here we live and work with 17 million people, most of them in the lowest western part of our country. Nevertheless we have highly developed agriculture, flower cultivation, urban, industrial, recreation and nature conservation areas. For all these types of land use high quality integrated water management plays a major role. It enables us to offer our people good living and working conditions. It also enables us to be the second largest exporter of agricultural products in the world, and to pay due attention to nature conservation and protection of the environment. Over the centuries our drainage pumping stations have evolved from to initial drainage by gravity through the discharge sluices to drainage by pumping by fully automatic pumping stations. We have learned from the many cases of flooding in our history. Nowadays our land is the best protected Delta in the World by the inland dikes, the river dikes, the dunes and sea dikes along the coast, and the storm surge barriers. Because of this water plays a major role in the Dutch society. Among others, this is reflected in many names of cities and villages, as well as in family names and sayings. Water and protection against flooding also plays an important role in childrens books. The role of water is also reflected in the access gates of old cities. With respect to this it is important that up to the middle of the 19th century by far most of the transport was over the water. Only by that time there was the change to transport over land. In future climate change is important, but not the main issue. The main issues are: -basically living and working up to 6.5 metres under mean sea level is not sustainable -we can only do this because of devoted operation and maintenance and timely modernization and upgrading of our water management and flood protection systems -key question is - How long will the Dutch society be able to maintain this cultural attitude? The relevant and characteristic aspects of the development and future of the lowlands of the Netherlands will be presented in the paper

Robert Halliday - N/A

Ryan Husband - Saskatchewan Irrigation Infrastructure Management System - In Canada, many municipalities have focused on the addition and expansion of their irrigation infrastructure. Most of this infrastructure has not seen a full life cycle, so it is difficult to plan and fund the rehabilitation and replacement of it. It is imperative this information is collected, so at the Ministry of Agriculture, we have been looking at how to assess and address the condition of the irrigation infrastructure in five irrigation districts around the province of Saskatchewan. ESRI, a company that provides geographic information services, was chosen as the database platform that the Ministry would use to evaluate and asses the infrastructure. Information was collected in the field using iPads, and other handhelds, with ESRIs Collector App which allowed for the inspectors to collect data in real time, at a specific geographic location. Data that was collected included the condition rating, consequence of failure, frequency of failure and other pertinent observations which allowed the Ministry to use evaluative matrices to assign a condition to the structure. The infrastructure was then given a replacement cost, with the information being provided from an engineering firm. The information collected is being used to make informed decision which supports both government and irrigation district objectives. The data has been used to develop irrigation rehabilitation programming which the provincial government uses to support irrigation districts. It also is used to develop Infrastructure Management Plans (IMP) for each irrigation district. The IMPs will be used by Irrigation Districts to plan their annual rehabilitation work and to strategically invest for future infrastructure requirements.

Kelly Farden - Sub-surface tile drainage project at the Canada-Saskatchewan Irrigation Diversification Centre - The Canada-Saskatchewan Irrigation Diversification Centre (CSIDC) is a 120 hectare irrigation research farm located in Outlook, Saskatchewan. The farm was initially developed in 1949 for flood irrigation but has gradually, overtime been converted to low-pressure sprinkler irrigation systems. The farm is now equipped with five low-pressure center pivot systems and 6 low-pressure linear systems which irrigate the various fields which range in size from 2 ha to 54 ha. Over the years, certain fields at CSIDC have experienced water-logging and salinization due to poor water management and/or excess moisture. Previous research at CSIDC demonstrated that sub-surface tile drainage installation in conjunction with a strategic fall leaching program can be effective at reclaiming these areas back into productive land. In the spring of 2017 a sub-surface tile drainage system was installed on approximately 6 ha of poorly-drained, salinized soils on field 12 at CSIDC. The intention of this installation was to lower the water table and then to actively œleach • the salts downward in the soil profile with the addition of irrigation water. A tile lay-out plan was designed based on site specific soil and topography considerations. Briefly, field 12 consists of fine sandy-loam to loam textured Bradwell soils overlying moderately fine textured silty-lacustrine deposits. The tile lines were spaced at 14 meter intervals and were installed at a depth of 1.2 meters. Following the installation the field was worked to level out any remaining ruts and then seeded to a cover crop of spring wheat. The field was irrigated periodically throughout the summer to match crop demand. The wheat crop was cut green and baled in late August. Throughout the month of September approximately 25 cm of leaching water was applied to the field. Water was reported to run out of the tiles within days of the first leaching application and then continued to run for the remainder of the month. In an effort to improve water infiltration, the field was deep-ripped in mid-September. Following this operation, most of the water applied was able to infiltrate into the soil and percolate downwards. An EM38 survey was conducted and benchmark soil samples were collected in the spring of 2017 prior to the tile installation. This survey captured the baseline salinity level of the field. Salinity zones were classified within the field as non-, slight, moderate, and severe. Following the fall leaching operation the field was re-surveyed and soil samples were again collected from the benchmark locations. A comparison of the pre- leaching and post-leaching EM38 maps did not reveal any significant difference in the salinity profile following the first year of leaching. However, when comparing salinity levels in the benchmark soil samples there does seem to be an indication of downward movement of salts. Soil sample locations #2 and #3 which were classified as moderately and severely saline respectively in the spring were both found to have decreased salt levels following the leaching application. Soil samples #4 and #5 which were classified as slightly to non-saline respectively in the spring did not seem to change much following the leaching application. Soil sample #1 which is located in the dry-land corner was actually found to have higher levels of salinity in the fall than it did in the summer. An overview of this project as well as a long-term salinity monitoring project at CSIDC will be presented.

W-B-01: Climate smart agriculture and innovative technologies for enhancing water use efficiency (I)

Jay Bauer - Utilizing Plant Response Indices for Delineating Intra-field Irrigation Management Zones - Variable rate irrigation is a precision agriculture technology that can increase water use efficiency by applying varying amounts of water to different zones in a field to account for variability in crop water requirements. Variable rate irrigation has the potential to decrease global water demand and make irrigation agriculture more economical for producers. This project evaluates several variable rate irrigation zone delineation methods for their ability to identify variability in spatial and temporal soil water storage on a 16-ha irrigated wheat field near Outlook, Saskatchewan, Canada. Near-infrared and thermal infrared indices of plant response were investigated for their ability to measure crop response of variable soil moisture conditions. These remote sensing plant response methods have been evaluated against traditional zone delineation methods, including soil apparent electrical conductivity mapping and yield mapping, to determine which methods are best suited for delineating irrigation management zones. Early findings indicate that each zone delineation method can provide useful data about soil moisture variability and that each method has different strengths and weaknesses depending on several environmental circumstances. Improving and understanding the suitability of irrigation management zone delineation methods will make variable rate irrigation a more efficient and economical tool for irrigation producers to utilize.

Maik Wolleben - Microwave Soil Moisture Sensing from Pivot Irrigation Systems - Skaha Remote Sensing Ltd. has developed a system comprised of highly sensitive, passive microwave sensors for mapping soil moisture from centre-pivot and linear irrigation systems. Several P-band radiometers are mounted on low-pressure irrigation systems and allow measurement of root zone soil moisture during pivot operation. The sensors are installed on horizontal mounts to remotely sense moisture of the soil ahead of the moving pivot. The wide bandwidth of the dual-polarized microwave sensors allows 3-dimensional mapping of soil moisture for an entire crop field at different depths; typically down to about 25 and 50 cm depth. This sensor system can help improve irrigation management by providing detailed information on soil moisture conditions and thus help use water more efficiently, increase yield, and reduce crop loss due to over or under-irrigation. We will discuss results from initial field trials in 2017 conducted together with Agriculture Canada in Outlook, SK, as well as present and review data collected this summer over several fields across Canada as part of a project funded through the Build in Canada Innovation Program. Accuracy, reliability, and benefits to the farmer will be discussed.

Edwin Kanda - Simulation of soil water dynamics under Moistube irrigation - The design and management of irrigation systems require knowledge of soil water movement. Moistube irrigation is a relatively new type of irrigation similar to subsurface drip irrigation. However, instead of emitters, water flows out of the Moistube nano-pores as a function of soil water potential and operating pressure. It supplies water continuously over the entire cropping cycle thereby minimizing plant water stress. Being a new technology, there is little information on its soil water dynamics. This study aimed at determining the soil water distribution experimentally and numerically using HYDRUS 2D/3D model for two soil textures (loamy sand and sandy clay loam). The experiment consisted of a soil box filled with soil and Moistube, supplied with water under a constant pressure head of 60kPa, placed at 20 cm below the soil surface. The soil water content was measured using MPS-2 sensors installed at depths of 5 cm, 10 cm, 15 cm, 20 cm, 30 cm, 40 and 50 cm and laterally at 10 cm, 20 cm and 30 cm. The soil water contents were measured over a period of 72 hours. The root mean square error values ranged from 0.01 cm3/cm3 to 0.07 cm3/cm3 and R2 of between 0.84 and 0.93 indicating that the simulated values agreed satisfactorily with the observed values. The model slightly under-estimated the soil water content with percent bias less than 15% in most of the observation points. There was no significant difference ($p > 0.05$) between the soil water distribution in lateral and downward direction for both sandy clay loam soil and loamy sand. However, the soil water content upward of the Moistube placement depth was significantly lower than both the laterally and downwards soil water contents ($p < 0.05$) in loamy sand where the soil water contents at 10 cm upward, downward and lateral after 24 hours were 0.08 cm3/cm3, 0.23 cm3/cm3 and 0.20 cm3/cm3 respectively. On the other hand, the corresponding values for sandy clay loam were 0.28 cm3/cm3, 0.32 cm3/cm3 and 0.31 cm3/cm3 at 10 cm upward, downward and lateral respectively. Soil texture had a significant effect on soil water movement with upward movement faster in sandy clay loam than in loamy sand. Being a continuous irrigation, the wetted distance over 24 hour period is important. For the applied pressure of 60 kPa, the lateral and downward distances were 23 cm and 24.6 cm respectively for loamy fine sand after 24 hours. Similarly, for sandy clay loam, the lateral and downward distance was 19 cm. This should be taken into consideration in the design of Moistube irrigation in terms of depth of placement and lateral spacing. The results of this study demonstrated the usefulness of HYDRUS-2D/3D model in the prediction of soil water movement for optimum design of irrigation systems and improvement of water use efficiency. Further investigations need to be carried out to determine the effect of pressure head and a variety of soil textures on the soil water movement under Moistube irrigation. Since crops have different root characteristics, soil water dynamics under Moistube irrigation considering root water uptake needs to be investigated.

Kazumi Yamaoka - Tropical Perennial Rice farming systems (SALIBU technology) for the 2nd Green Revolution against climate change - Detailed Abstract:1. Background Is there anybody who has seriously explored the dramatic increase in the annual yields of rice after the majority of rice farmers received the benefits of the Green Revolution? Who would have imagined that the yield of the rice ratoon crop was equivalent to that of the main crop and that the cultivation of rice ratooning was, therefore, able to continue over generations as a perennial crop? Ratooning is a method of harvesting a crop which leaves the roots and the lower parts of the plant to grow as a ratoon or the stubble crop. Many studies on rice ratooning were published by the IRRI and successive researchers, but rice ratooning was always regarded as just a one-generation supplementary crop with no successors because of its low yield generally ranging from 20% to 50% of the main crop. However, Tropical Perennial Rice (ToPRice) farming systems (SALIBU technology) originating from West Sumatra, Indonesia allow for harvesting rice grain up to 3.5-4 times annually and produce a yield for each ratoon crop at the same level as that of the main crop in Indonesias tropical or sub-tropical, winterless climate. There are over one hundred countries globally that cultivate rice with annual production figures above 715 and 480 million tons of paddy and milled rice respectively (FAO, 2013) and 3.5 billion people who consume rice worldwide (IRRI, 2013). Rice is one of three major grain crops that act as the staple food for people all over the world; the importance of rice in Asia, which contains 60% of the worlds population cannot be understated, and recent increases in rice consumption in Africa are also noteworthy. The demand for rice from Sub-Saharan African countries is steadily increasing, replacing much of the existing coarse grains such as sorghum and millet, and starchy root crops such as taro, cocoyam and cassava as the major source of dietary calories. Consequently, the consumption of rice in Sub-Saharan Africa is estimated to increase from 19.8 million tonnes in 2010 to 34 million tonnes in 2020 (Africa Rice Center, 2011). As a result, about 14 million tonnes of milled rice will be imported into the region in 2020 to meet the increasing demand. 2. Justification The majority of rice production in Asia and Sub-Saharan Africa depends on an enormous number of small-scale rice farmers for whom rice is an important source of nutrients as well as income. However, it is difficult for small-scale rice farmers with a poor investment capacity to increase their cultivated area. It is unrealistic for them to aim for large-scale rice farming, and even if they do somewhat increase their yield per acre within a limited cultivation area, they cannot expect a substantial increase in income. Conventional strategies cannot adequately contribute to increases in rice production that must continually meet increases in demand both now and in the future. Therefore, a new strategy, namely the introduction of Tropical Perennial Rice (ToPRice) farming systems (SALIBU technology) to small-scale rice farmers, should be studied to help lead the 2nd Green Revolution. Rice is always cultivated as a monocarpic annual plant. However, in tropical areas it can survive as a perennial plant so that it can continue to produce ratoon crop grains over generations. The ToPRice farming systems have overcome the two disadvantages of conventional rice ratoon cultivation: low yield, and the different times of heading and the varied optimum harvesting period between stems in a stubble or between stubbles due to the difference in the growth rate of ratoons.

However, this technology has only been developed in recent years and is not yet well known nor being studied except in Indonesia. Moreover, no study has been conducted on the impact these farming systems have on saving irrigation water; introducing these systems should improve water productivity because farmers can reduce the amount of irrigation water they use by shortening cultivation periods and save water no longer needed for unnecessary seedling nurseries, puddling and transplanting. It is useful adaptation against climate change. 3. Research method Therefore, the authors of this paper started collaborative research aiming to apply ToPRice farming systems (SALIBU technology) in countries other than Indonesia and evaluating their impact on water productivity. To explain SALIBU technology, a new paddy plant is grown from the stubble of an old plant after cutting its stem at a height of 3 to 5 cm above ground level one week after its harvest, once it has reached physiological maturity under field capacity soil moisture conditions. Then, shoots will appear from nodes located on the surface level of the ground. The nodes will also germinate new roots so that the absorption of nutrients from the soil does not depend on the old plant anymore. This mechanism has produced strong growth in new paddy plants, and productivity is increased and even higher than the old plant. We set up target areas in the Central Dry Zone (CDZ) in Myanmar that covers more than 54,000km3 and contains 36% of its population, and in regions in coastal savannah agricultural ecological zones of Ghana where irrigated paddy rice agriculture is already developed. In the CDZ, we have conducted preliminary experimental trials in 15 large pots (2.4m x 1.8m) using a popular local rice variety and continuous cultivation tests over generations under these systems. Data for the yield component for each generation was accumulated. In parallel with these tests, we constructed 36 paddy plots of about 32 square meters each equipped with water-impermeable plastic sheets for suspending the horizontal percolation of water in the soil. The set-up included combining three varieties of rice and three cultivation water management methods with four replications. Data from the continuous cultivation tests and water productivity comparison tests were acquired at the same time. It is known that the Asian rice varieties Japonica and Javanica of the Oryza sativa subspecies have stronger characteristics as a perennial plant than African rice varieties of the Oryza glaberrima subspecies. Therefore, the authors are carrying out field trials to determine more applicable rice varieties that can perform well under these systems in coastal savannah agricultural ecological zones of Ghana as well as for evaluating the water productivity of the systems. We started to conduct the experimental trials in 54 containers (1m x 1m) with five Asian and four local rice varieties. 4. Results In the CDZ, we started the preliminary experimental trials in 15 large pots in July 2016 and these have already proved that continuous cultivation under these systems has lasted over generations with a higher yield than that of the main crop. Plants of the fifth generation of the ratoon crop have been growing under these systems and were just harvested in April 2018. The main crop of a popular local variety, Thee Htat Yin, produced a yield of 5.3 t/ha with the subsequent first to fourth generations of the ratoon crop producing yields of 9.1 t/ha, 6.9 t/ha, 11.5 t/ha and 6.9 t/ha respectively. The interval between harvests of the ratoon crop is about 101 days on average. This is 14 days shorter than the period from sowing to harvest by conventional cultivation methods. The yield of every generation of ratoon crop exceeded that of the main crop. Therefore, these results demonstrate that the ToPRice cultivation system worked well for almost two years under the climate in the marginal areas of the CDZ. Continuous cultivation and water productivity comparison trials in the test field started in July 2017, with the main crop being harvested in October of the same year and the ratoon crop in January 2018. For two popular local rice varieties (Thee Htat Yin and Sin Thu Kha), the standard ToPRice farming systems (SLB) and these same systems with AWD water management applied to them (SLB+AWD) produced a ratoon crop yield (4.59-5.91 t/ha) that was the same level as that of the main crop (4.47-5.86 t/ha), and also exceeded the yield produced by trials using the conventional practices of cultivation method (CP) that was carried out at the same time as the SLB and SLB+AWD trials. In terms of water productivity (g/l), SLB (1.40-1.76) and SLB+AWD (1.47-1.92) were 2.3 to 2.6 times more productive than CP (0.61-0.73), resulting in a saving of about 60% of the amount of irrigation water used for a units yield. Based on the above results, it is suggested that an annual yield can almost be doubled by reducing annual irrigation water consumption by about

20% in a unit of land by switching from CP (double cropping) to SLB. In Ghana, West Africa, we harvested the main crop of five Asian and four local rice varieties in January to February 2018 and plants of the first generation of the ratoon crop under the systems are being cultivated for harvest. 5. Considerations and recommendations Tropical Perennial Rice (ToPRice) farming systems (SALIBU technology) have great potential to contribute to the realization of the 2nd Green Revolution of which small scale farmers will be the main beneficiaries. Further studies on appropriate rice varieties, climate, water and soil condition, mechanisms that bring about high ratoon crop yields, economical and ecological benefits and risks, and social problems regarding ToPRice farming systems should be carried out by researchers worldwide.

W-A-02: Irrigation, drainage, and flood control for resilient agriculture (I)

Vijay Labhsetwar - Irrigation and Drainage for Global Food Security - The World, as a whole, has been making steady progress albeit slowly towards improved food security and nutritional status during the past half a century. Humanity is thus still faced with the stark reality of a chronic under-nutrition affecting some 1.02 billion people, more than 20 percent of the population of the developing countries, as many as 37 percent in sub-Saharan Africa and still more in some individual countries. The notion that the world would by now be eliminating the scourge of hunger and under-nutrition has so far proven overly optimistic. The role of Water Resources Development (WRD) is going to be increasingly important with growing population and declining world food grain production, since food yield response to irrigation is almost double as compared to rain-fed agriculture. Human societies will continue to rely on areas under irrigation for food security. Presently 280 million ha of land is irrigated accounting for 18 per cent of total arable and cropped area (1554 Mha) in the world. This means that crops are grown on 1084 Mha without a water management system (drained lands 190 Mha). Therefore, there is tremendous scope to increase area under irrigation by way of more storage dams, where possible, specially in Asia and Africa. Further, potential irrigation demand will grow in developing countries, while it will actually decline in developed countries. The fastest growth in potential demand for irrigation water will occur in Sub-Saharan Africa and in Latin America. Each of these regions has a high percentage increase in irrigated area from a relatively low 1995 level. Unless, the aforementioned irrigation potentials are developed, population expansion will force millions of impoverished people to undertake unsustainable farming systems. The country case studies suggest the following issues / approaches / policies that could be considered responsible for achieving food security: (1) restructuring of the public finances; (2) conducive institutional framework; (3) research and dissemination of new technologies; (4) emphasis on antipoverty policies; (5) holistic approach to agriculture; (6) provision of irrigation and high yielding varieties, fertilisers and pesticides; and (7) extensive social safety nets etc.

Seija Virtanen - Effect of controlled drainage and sub-irrigation on groundwater level, drain discharge, nutrient loadings and yields - The focus of this study was to get a larger view on the effect of controlled drainage on groundwater level, run-off, nutrient leaching and crop yields. We surveyed the results of the old as well as ongoing field experiments concerning controlled drainage and sub-irrigation in Finland. The data consists of field experiments which represent various types of soil from mineral to peat soils. Controlled drainage and sub-irrigation have been proposed an option to decrease nutrient leaching from agricultural fields. In the studies carried out in different countries under humid climate it was found that in dry summers controlled drainage enhanced yields by way of providing water for transpiration. In addition, the total leaching of nutrients was found to decrease. The main reason for the decreased leaching was decreased runoff but also lower nutrient concentrations in runoff waters due to denitrification of nitrate and sorption of phosphorus. In Finland, controlled drainage and sub-irrigation have been studied in order to improve the quality and quantity of yields already in the beginning of the 20th century. At that time dry summers prevailed and crops suffered from droughts. However, subsequently the technique was set aside when normal and wet summers occurred and drainage was the most important issue. The interest in controlled drainage studies rose again in the 1990s focusing on the mitigating of nutrient loads from cultivated fields. As a result of these studies the decrease in nitrogen leaching by controlled drainage was calculated to be 15% compared to conventional subsurface drainage. Accordingly, farmers started to get subsidies to their investments in controlled drainage and its maintenance in Finland in 1995. Later on feasibility of controlled drainage and sub-irrigation of decreasing harmful environmental effects of drained acid sulfate and peat soils have been investigated. At the moment environment subsidies for controlled drainage and sub-irrigation are granted to acid sulfate and peat soils only in order to mitigate acid loadings and to decrease greenhouse gas emissions. Until now controlled drainage has been implemented on an area of ca. 70 000 ha. However, it has been estimated that controlled drainage would be feasible for 600 000 " 800 000 ha of agricultural fields. All the surveyed controlled drained fields were very flat (slope < 1%) and thus suitable for controlled drainage. The field measurements indicated that the groundwater table level in the single fields under controlled drainage dropped sharply below the drain depth during dry spells. In the studied sub-irrigated fields the pumping of water into the drainage system was found to increase groundwater level but not in the furthermost field area. However, in dry summers shortage of water has restricted sub-irrigation. The effect of controlled drainage on drain discharge was estimated using occasional manual measurements. No drain discharge was observed from the controlled drained fields even though there was drain discharge from the fields without control at the same time. In the ongoing acid sulfate soil field experiment the drain discharge has been continuously measured. There the annual drain discharge decreased from 9% to 39% due to controlled drainage. Slightly decreasing trends were observed in the concentration of nitrogen in the drain discharge in the fields. However, the differences were not significant. On the contrary, the total phosphorus concentration increased significantly in the discharge water of the controlled and sub-irrigated fields in acid sulfate soil. This phenomenon might be related the reduction of iron and aluminum oxides, which serve sorption places for phosphorus. In the surveyed acid sulfate soil fields, phosphorus concentrations in drain water was very low, 20 " 30 Âµg l-1, contrary to nitrogen concentrations which were up to 32 mg/l. Based on the results from the surveyed controlled drainage fields the decrease in drain discharge means decrease in nutrient leaching. In the acid sulfate soil experimental field, the decrease of drain discharge by the 50 mm would mean a decrease in the total nitrogen load by 8.5 kg ha-1 year-1 (the average long-term Ntot concentration of drain water in the experimental field 17 mg l-1) and in the total phosphorus load by 0.01 kg ha-1 year-1 (the average long-term Ptot concentration of drain water in the experimental field 20 Âµg l-1). The crop yields have been increased and the quality of crop has improved by controlled drainage and especially by sub-irrigation. The most pronounced effect has been found on potatoes, crop yield of which increased by 80% compared to a field without drainage or irrigation at the same year. The respective increase in the crop yield of barley was 40%. In an 8-year-long study period in an acid sulfate soil, no statistical differences were detected in crop yields among conventional drainage, controlled drainage and sub-irrigation, but differences in the yields varied annually. For example in a dry growing season, the crop yield of barley was increased by 920 kg/ha (20%) and 370 kg/ha (8%) by sub-irrigation and controlled drainage, respectively, compared to conventional drainage (4690 kg/ha). In a rainy summer, however, the conventional drainage system gave 140"450 kg/ha (2"7%) higher crop yield of wheat compared to controlled drainage (6790 kg/ha). There were no statistical differences in test weights of grain (hectoliter weight and 1000 seed weight). The importance of controlled drainage will be pronounced due to the climate change, which has been predicted to cause more frequent and higher rainfalls causing further increase in nutrient leaching in Finland. Furthermore, irrigation might be needed in a larger scale than nowadays to ensure profitable crop production. To improve function of controlled drainage and sub-irrigation effective management of water table level in a single field and also in a main ditch is needed. Therefore, automatic valves (Water Gate) in collector pipes and control wells and an automatic dam powered by solar energy are being studied.

Abraham Joel for Olive Tuyishime - Controlled drainage for reducing nitrogen losses and salt concentrations in a clay soil under rice production in Rwanda - Drainage water has been recognized as one of the causes of agricultural non-point pollution. Controlled drainage has a large effect in reducing nitrogen loads in drainage outflow in comparison to conventional drainage. However, few studies have investigated the effect of controlled drainage on salt dynamics in soil. Furthermore, rice paddies are major source of greenhouse gases (GHGs). Pronounced GHGs losses result from midseason drainage and dry-wet episodes in paddy fields. A three cropping seasons (CSs) field experiment was conducted at Muvumba marshlands, in Eastern part of Rwanda to assess the effect of controlled drainage in managing salt concentrations in soil and nitrogen losses. The experiment entailed 12 plots (8x8 m), arranged in a randomized complete block design with four blocks and three treatments which are conventional shallow drain: CV60cm (control), deep conventional drains (CV120 cm) and controlled drainage (CD 120cm). The soils are derived from granitic or igneous parent materials. Rice was used as test crop. The soil and water salinity was regularly monitored using electric conductivity probes; the drainage outflow was measured using HS Flumes and level sensors. Nitrogen concentrations in soil and drainage water were determined in the laboratory. A static chamber method was used to collect gas samples, which were analyzed with a gas chromatograph. The results on soil salt content were statistically different in all three cropping seasons ($P<0.05$). High salt content in soil were observed in CV60cm (mean 2.53 mS/cm, 3.43 mS/cm and 4.40 mS/cm) compared to the CV120 cm (mean 2.31 mS/cm, 3.30 mS/cm and 4.27 mS/cm) in three CSs respectively.The CD 120cm showed a reduced drainage outflow (mean 9.96 mm/day) compared to CV120 cm (10.89 mm/day) with outflow reduction of 8.5 % and therefore it contributes to saving irrigation water. Measurements on nitrogen concentrations showed that CD 120cm had a reduced nitrogen output (mean N03_N of 0.69 mg/l and NH4-N of 0.39 mg/l) compared to CV120 cm (mean N03_N of 0.81 mg/l and NH4-N of 0.42 mg/l).

Jason Drury -Irrigation in Saskatchewan - Early explorers felt that the region now known as southern Saskatchewan was uninhabitable, describing it as an arid desert. Irrigation played a role in its initial settlement. When the Province of Saskatchewan was first formed in 1905, there were 110 irrigators operating 304 kilometers of canals. Following severe droughts in the 1930s, the provincial and federal governments increased their support for irrigation. This included the development and enhancement of water resources, which resulted in the creation 26 reservoirs and more than 15,000 hectares of irrigation. Saskatchewan currently has 146,000 hectares of irrigation. This accounts for less than one per cent of its arable agriculture lands. There is a tremendous opportunity for growth. Lake Diefenbaker was created in 1966 following the construction of the Gardiner and QuAppelle dams. It is located in south-central Saskatchewan and has a capacity of 8.9 million cubic decametres. Currently, only two per cent of Lake Diefenbakers annual average inflow is consumed for irrigation, which accounts for a combined area of 44,500 hectares. As with farming practices in general, irrigation in Saskatchewan has evolved greatly over the years. Irrigation systems have changed from predominantly gravity to low-pressure sprinklers. Farmers can now operate their irrigation systems remotely with the push of a button. Variable rate irrigation allows for the precise application of water where it is needed most. Cropping choices are ever expanding and there are more varieties than ever. The evolution of irrigation has created many new opportunities for processing and adding value to crops. All of this has helped contribute to strong and vibrant rural communities. There are a number of government and industry stakeholders involved with irrigation in Saskatchewan. Both the provincial and federal governments continue to strategically invest resources to support industry growth and profitability. Two non-government industry groups provide education and promotion of best practices. Farmers work together as groups and as individuals to construct, operate and maintain irrigation infrastructure. All of the different groups share a common goal of supporting growth and development of irrigation in the province.

Maher Salman Solar powered irrigation for sustainable agricultural development AND Harvesting water to grow resilient agro-ecosystems and livelihoods in the face of climate change - N/A

W-B-02: Climate smart agriculture and innovative technologies for enhancing water use efficiency (II)

Dale Tomasiewicz -Micronutrient Requirements of Irrigated Crops in Saskatchewan, Canada - Most of Saskatchewan's 100,000 ha of irrigation is practiced on chernozemic soils in a cool semi-arid climate. Soil texture varies widely. The crop mix is more diverse, and yields are much higher, under irrigation than for the local rainfed production. Studies have shown that micronutrient deficiencies for crop production are not extensive in Saskatchewan in general, nor under irrigation in particular. Copper is the minor nutrient of most concern, followed by zinc - both can be present at insufficient levels for maximum yields on coarse soils. However, use of fungicides containing substantial amounts of Cu and/or Zn on some of the higher-value irrigated crops has reduced the likelihood of the deficiencies on a substantial portion of the irrigated lands.

John Hornbuckle -IrriSAT - An Australian experience in the development and use of innovative technology for enhancing water use efficiency - Water availability is the most limiting factor of crop production in semi-arid irrigation areas throughout the world. Under climate change scenarios many semi-arid irrigation areas are predicted to become dryer and have reduced access to water for irrigation. In Australia, during the last decade there has been a considerable effort aimed to optimize water management in irrigated agriculture in order to improve water use efficiency and produce more crop per drop. An irrigation schedule adjusted to the actual crop water requirements is crucial to better use the available water resources. Historically, weather based irrigation scheduling techniques were not widely adopted in the irrigation industry due to the problem of determining site specific crop coefficients (Kc). However, with the use of the new remote sensing satellites and information delivery platforms such as Google Earth Engine these methods have gained considerable traction in irrigation industries within Australia as they offer low cost and high spatial coverage options for providing site specific water use and benchmarking information. This presentation describes the IrriSAT Tool https://irrisat-cloud.appspot.com/# developed in Australia and its extensive use by irrigators and water managers as a tool for irrigation water management. IrriSAT is a cloud based app using the Google Earth Engine to provide irrigation management and benchmarking information from remote sensing technologies (Landsat and Sentinel) across large spatial scales. The IrriSAT app automates satellite processing and information delivery of satellite data and provides irrigators with water management information across a range of scales to assist in irrigation scheduling and crop productivity benchmarking. Spatial crop water use information determined by IrriSAT allows users to investigate water use differences within and between fields. Identifying over/under performing fields allows users identify issues driving water use productivity. Information in IrriSAT is updated on a daily basis automatically and also includes a 7 day crop water use forecast so irrigators can predict water demands into the future. Examples of the use of IrriSAT for irrigation scheduling and industry wide benchmarking will be given in the presentation.

Jarett Powers - In-situ Monitoring and Application of Passive Microwave Sensors for Variable Rate Irrigation Systems - Access to timely and accurate soil moisture data is an important data variable for weather forecasting, climate modeling, floods forecasting and modelling hydrological and biophysical systems. The information spans the sectors of agriculture, forestry, environment, water management as well as public health and safety. For agriculture, soil moisture is vital for predicting irrigation water needs, forecasting crop production and monitoring risks associated with floods/excess moisture, drought, pests and crop diseases. Agriculture and Agri-Food Canada (AAFC) has worked extensively to successfully develop the processes to derive soil moisture information from satellites. AAFCs research has been focused on RADARSAT-2 and other synthetic aperture radar (SAR) satellites to produce surface soil moisture maps at a medium (20m) resolution. AAFC is also partnered with NASA on the Soil Moisture Active/Passive (SMAP) mission. SMAP uses a passive microwave sensor to produce surface soil moisture maps on a global basis at a coarser (9km-33km) resolution, every 2-3 days. Recently, AAFC began collaborating with Skaha Remote Sensing to explore the use of passive microwave sensors mounted on irrigation equipment and in-situ soil moisture sensors to produce soil moisture maps for variable rate irrigation planning. This presentation will highlight results from current field studies, discuss in-situ monitoring and provide an overview of current satellite soil moisture development and applications of the data.

W-A-03: Irrigation, drainage, and flood control for resilient agriculture (I) AND Irrigation infrastructure development (I)

Bruce Jones - China's Irrigation, Drainage, and Flood Control Legacy -The Chinese have documented a four thousand year legacy of irrigation, drainage, and flood control. They have devised an enormous variety of water management schemes to address their needs, mostly based on a very inexpensive labor pool. Many schemes were never completed, and many were unsuccessful from the beginning, for a variety of reasons, including just bad luck. Some schemes were wildly successful, if only for a few years or generations, and in at least one case for over a thousand years. In this paper we will briefly describe strategies large and small, and describe the Why and How of their creation. And the duration of their success, if any.

Kwang-Sik Yoon - Evaluation of Resilient Water Supply Alternatives for a Large Irrigation Reservoir According to the Drought Scenarios - The resilient infrastructures not only reduce the damage scale by various disasters, but also minimize the social cost by reducing the recovery time. Among various natural disasters, drought is not easy to judge accurately in time and space because the nature of drought is slow in progress, unlike floods and other natural disasters. Therefore, it is urgent to establish a standard plan for the shortage of agricultural water. It is necessary to study the resilience of agricultural infrastructure when considering frequent natural disasters such as floods and droughts due to abnormal climate. In this study, after selecting the representative reservoir in the Yeongsan River basin among the agricultural reservoirs managed by the Korean Rural Community Corporation (KRC), we propose alternatives to the water shortage by the drought scenarios assumption. The optimal water supply strategy was evaluated by using the robustness-cost index (RCI). In this case, the initial rate of water storage of reservoir was analyzed as 4 cases (70%, 60%, 50%, and 25%) under rainfall scenarios 50, 60, 70, 80 of normal annual rainfall. The water balance analysis for each drought scenarios was carried out to calculate the required quantity, supply capacity of Naju reservoir. Hydrological Operation Model for Water Resources System (HOMWRS) was used. Four structural alternatives were selected to estimate the robustness index (RI) and the cost index (CI) to obtain the RCI values. Structural alternatives are classified into temporary measures and permanent measures. Temporary measures include the installation of tube wells or portable pumps, while the permanent measures include the installation of a pumping stations and the pumping water to the reservoir (Yeongsan River-Naju reservoir). RCI values were higher in permanent measures than those of temporary measures. Initial storage of the reservoir also affected RCI values of the drought measures. Permanent measures installation at the early stage of the reservoir storage shortage was identified as the most resilient system.

Pheerawat Plangoen - The Development of Concrete Lined Ditches Mix with Rubber Latex for Farm Irrigation System - This study analyzed the physical and mechanical properties of concrete mixed with rubber latex (pre-vulcanized latex) for the development of irrigation canals. The experiment was performed in a laboratory to test the properties of the mixture in terms of workability, bleeding of concrete, compressive strength, tensile strength, flexural strength, bond stress and water absorption ratio. To test the performance Polymer and cement (P/C) were mixed in different proportions of 0%, 5%, 10% and 15% by weight to prepare the solution and was further added to concrete, used to construct the irrigation ditch. Water and cement were mixed in the proportion of 0.62 (w/c) and the strength of the structure was tested after 7, 14 and 28 days respectively. The results indicated that the polymer cement ratio (P/C) of 5% gives the best performance with 216.60 ksc compressive strength, 26.05 ksc tensile strength, 44.64 ksc flexural strength, and 24.06 ksc bond stress. The average water absorption of the irrigation ditch prepared with P/C mixture of 5% was 1.03% and it had a seepage loss of 3.4 mm/day as estimated by Hortons equation. The experiment showed that irrigation ditch prepared with P/C mixture of 5% can reduce the seepage loss by 45% as compared to ditches prepared without polymer (P/C mixture of 0%). Thus this study recommends that polymer cement ratio (P/C) of 5% by weight is most suitable for construction of irrigation ditches. The material used in construction of irrigation ditch was consist of portland cement 50 kg, sand 135 kg, gravel 148 kg, water 30 kg and rubber latex 2.5 kg. For field research in irrigation lining ditch having the bottom width of 0.4 m, height 0.3 m and thickness 0.07 m were constructed using the recommended mixture. The preliminary evaluation of the ditches in the field also indicate that these ditches allow water to flow quickly and easily. With 45% reduction in the seepage loss the irrigation efficiency has improved significantly.

Hafiz Faizan - Best Management Practice for a Solar-Powered Center Pivot Irrigation System - The adoption of photovoltaic (PV) technology in irrigated agriculture has been rapidly growing in recent years due to a wider availability of affordable PV modules, and a desire to reduce dependencies on conventional non-renewable energy resources. The power requirement for an irrigation system is strongly linked with depth of water application which is determined by the frequency of irrigation and associated time duration. The objectives of this research were to: (1) investigate the variability of PV system sizing under alternate irrigation management strategies; and (2) to identify a suitable management practice for minimum PV sizing. A model was used to optimize the PV system, based on the systems ability to maintain the soil moisture within desired limits, as defined by the irrigation management strategy. A small (1.4 ha) solar-powered center pivot irrigation system (79.3 L min-1 ha-1) installed at Outlook, Saskatchewan, Canada was used for evaluating management strategies that include moderate application depths (25-35 mm per application) and frequent light irrigations (5-10 mm per application). The strategy of using frequent light irrigations required a significantly smaller PV system than the standard soil moisture threshold based strategy. For example, six 200W @ 12V panels and 540 Ah battery capacity, as compared to ten similar panels with 1,080 Ah battery capacity, was required, to achieve an 85% system reliability when considering 2012 climate data. These results emphasize that the irrigation management strategy can have a significant impact upon the economic and technological feasibility of a PV irrigation system. The modeling tools demonstrated here can be used to determine the optimum size of the PV irrigation systems while taking into consideration the interrelated factors of irrigation management, soil water characteristics, and climatic variations.

S. Mehdy Hashemy Shahdany - Improving Water Delivery within Main Irrigation Canals in Arid Regions Using In-Line Reservoirs - Providing reliable amounts of water is not possible for most of the irrigation districts in arid regions due to water scarcity. Under this condition, the upstream and the downstream operational methods are not able to meet an equitable water delivery to downstream users as well as to upstream ones. New operational strategies should be implemented to improve fair water deliveries. One of the effective ways to deal with mismatches between downstream demands and upstream water supply and also to reduce long transmission time from head-gate to the end users is using off-line or in-line storage reservoirs. Although off-line regulating reservoirs help to maintain a balanced operation, they are heavily curtailed by environmental concerns; physical limitation (suitable topography for reservoir construction); costly maintenance activities; required automated service of structures between reservoirs and main canal to utilize the operational variations. Schuurmans et al. (1992) suggested using in-line storage in the main canal to create night storage in an irrigation system. This study assesses the operational performance improvement of the Roodasht main irrigation canal (Isfahan, Iran) using three pools as in-line reservoirs. By using 0.3-0.45 m of freeboard, three flat and long pools situated in the upstream, middle and downstream part of the main canal with a minimum number of turnouts, are considered as the in-line reservoirs. A simplified version of the mixed control method (Litrico and Fromion, 2009) is applied to control the water level in this research. Check structures downstream of each pool are regulated based on the adjacent upstream water level deviations from the target level. The flow change of each pool is sent to its upstream in-line reservoir, and the first in-line reservoir is coupled to the headgate and controls the released flow from the headgate. Linear Control Theory is used to design decentralized feedback PI controllers minimizing disturbance amplification according to van Overloop et al. (2005) and considering resonance behavior of water flow in irrigation pools by Schuurmans (1997). The control structure of the first pools is schematized as in Fig. 1. In this control system, the check structure of each pool is adjusted based on its measured water level. Inputs of an in-line reservoir controller are the errors of the reservoirs, cumulated flow changes of the downstream pools until the next reservoir and flow changes of the downstream reservoir. Figure 1. Scheme of designed mixed control configuration for first pools of the Dez canal ICSS hydrodynamic model is used to simulate the scenario of this study. Performance of the controller of this study is assessed by using controller performance indicators of the maximum absolute error (MAE), integral of absolute error (IAE) and the steady-state error (STE). According to the results, in the Roodasht main irrigation canal with several long and flat pools, applying in-line reservoirs would be a promising strategy to improve the existing operation. Water could be stored in the canal without neither adding any physical elements like off-line intermediate reservoirs nor increasing freeboards. Choosing middle and downstream pools as in-line reservoirs will compensate mismatches in supply and demand which mostly occurs for downstream users. Figure 2 shows the results of test scenario where the distance downstream is employed in the form of the mixed control. In this test, a constraint is imposed on the head-gate opening from the beginning of the simulation, and the inflow change happens at the first time step of the simulation as a decreasing inflow step changes. Figure 2 illustrates the discharge changes of the check structures and water level deviation of the canal reaches for the normal operational conditions. Due to the use of the feedforward control on the headgate, the gate flow change has a fast response to the known demand changes within the main canal. The feedforward controller calculates the delay times of water traveling in the canal to simulate the behavior of an experienced canal manager to adjust the head regulator. However, it should be noted that, although the feedforward control method takes the delay time into account, using this method of feedforward control for the head regulator of a canal with manual operation is risky due to unknown disturbances and friction variations in time. Comparing the Figs 2 (a) and (b) shows that the water level deviations and settling times in most of the pools are satisfactorily decreased when using in-line reservoirs and the appropriate control configuration. When the water level of a pool starts to increase, the local feedback PI controller in each pool tries to keep the water level close to the set point, and since it is coupled to its upstream reservoir, this deviation is hierarchically transmitted to the upstream in-line reservoirs and eventually to the head regulator. The stored water is used later by the water demand increases. According to the results, the filling and emptying pattern of the second reservoir is not similar to the other ones. This pattern implies that the stored capacity of the reservoir is busy with damping the water level fluctuation and making smoother released flow. The aforementioned satisfactory results of using in-line reservoirs are also confirmed by the operational performance indicators: MAE, IAE, and STE. The maximum values of MAE, IAE, and STE for the current operation are 1.8, 1.5 and 1.6, respectively, while these indicators after using in-line reservoirs are improved to 1.08, 0.39 and 0.91 respectively. Figure 2. Water level deviation within the Roodasht main irrigation canal (a) in normal operational condition and (b) using in-line reservoir operational strategy Acknowledgments Authors would like to acknowledge the financial support for this study provided by the Esfahan Regional Water Authority using the research project (ref. 96/128). References Schuurmans, W., Brouwer, R., and Wonink, P. (1992). IDENTIFICATION OF CONTROL SYSTEM FOR CANAL WITH NIGHT STORAGE. Journal of Irrigation and Drainage Engineering 118. Schuurmans, J. (1997). Control of

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W-B-03: Climate smart agriculture and innovative technologies for enhancing water use efficiency (III)

Caren Jarmain - Supporting farmers with satellite information increases their resilience and saves water: The FruitLook story - In recent years, the agricultural sector in South Africa (SA) has been hit hard by extensive and extreme drought conditions, resulting in widespread reduction in crop yield and quality. The Western Cape (WC) Province of SA remains in the grip of its worst drought in more than 100 years, with dam levels having reached extremely low levels and severe water restrictions and conservation measures put in place. The latter has had a great impact on the Western Cape agricultural sector, making the efficient use of water resources by farmers vital to remain productive. Over the past 8 years, FruitLook has helped farmers to better manage their farms and increase water use efficiency. FruitLook is an innovative service providing advanced satellite data products describing crop growth, water use and mineral content on a near-real time basis to the agricultural community. The service is free to all users and is fully funded by the WC Government Department of Agriculture. FruitLook currently has 650 regular users including producers, consultants and researchers. The knowledge gained through FruitLook is actively helping farmers prepare for a changing climate. In a recent online survey, 63% of users indicated that FruitLook made their water management at least 10% more efficient. Since 2010, much time has been invested in empowering users with a better understanding of what FruitLook brings - through users training sessions, visits and sharing success stories. In addition, much improvements have been made to the data provided and in making the service fully operational, providing new information timeously each week during the main growing season. FruitLook is currently used to plan, monitor and evaluate farming activities and many success stories exist showing how FruitLook has become an integral part of farm management activities. In an age with much technological development, farmers are harnessing the benefits from information technologies designed for agriculture and water management.

Allan Peake - Customizing irrigation strategy to soil type and climate using the APSIM crop model - Crop model application is typically categorised into use as tools for research, management and education. In Australia, crop models are being deployed ˜on-farm for each of these purposes in relation to crop water resources, impacting the majority of farmers in Australia either directly or indirectly. The APSIM (Agricultural Production systems SIMulator) model is being used throughout Australia as an education, management and research tool to develop customized irrigation strategies for wheat and maize for different soil types, locations and climates, with the aim of increasing water use efficiency, profitability and also to manage seasonal climate variability. In both rainfed and irrigated farming systems, management of stored soil water is important due the strong relationship between stored soil water at sowing and yield. The APSIM model is first used with farmers to communicate the concept of stored soil water by encouraging them to view soil as a ˜bucket that holds water available to the crop, which can vary in size between the extremes of 350 mm and 40 mm between crops and soil types. At a paddock scale, once the importance of soil water holding capacity is established, measurement of soil water available at sowing is used to initialise crop models within the APSIM framework, which is then used to forecast probable yield in response to intended inputs such as irrigation and N fertiliser, for a range of soil types, locations and/or climate. Simulation experiments can then be used to assess the optimum agronomic strategy for achieving maximum economic return, using different levels of irrigation and/or fertiliser in combination with other agronomic variables such as sowing dates, plant density and cultivar phenology. At a whole-farm level, the optimum whole-farm deficit irrigation strategy can also be investigated for a range of soil types, locations and seasons. In a recent case study deficit irrigation strategies were assessed for furrow-irrigation farms of north-eastern Australia that are typically water-limited during the winter, wheat cropping season. The APSIM model simulations showed that the optimum whole-farm irrigation deficit irrigation strategy was highly dependent on stored soil water at sowing and in-season rainfall, with 150mm of in-crop rain the approximate tipping point above which growing a larger area of deficit irrigated wheat was more profitable than growing a smaller area of fully irrigated wheat. The recommendations are now being used by farmers across north-eastern Australia to determine the best irrigation strategy for their soil type and location, in the context of the variable expectations for annual rainfall across the region.

Graziano Ghinassi - Sustainable Technology to Reduce Energy Use in Travelling Sprinkler Irrigation - Hose reel irrigation entails high energy consumption especially when water is supplied by big gun sprinklers. Despite much of the energy being used to put water under pressure, additional amount of energy is required for positioning (towing by tractor) and rolling (towing by reel machine) the travelling cart. Moreover, under field conditions such as missing cart lane (e.g., pipe to be unrolled over actual crop when complementary irrigation is practiced) or light rainfall just moisturizing the surface of clay soils (e.g., mud hindering the sliding movement of the pipe), positioning of a travelling cart supporting either big gun or boom sprinkler can be difficult. Critical conditions may occur also when long pipes are used and the tractive force of the tractor is inadequate (i.e., unable to completely unroll the pipe). On the other hand, larger tractors can overcome the problem, at the price of strong mechanical stress on the pipe (e.g., elongation), increased fuel consumption and higher investment and overheads. During pipe retrieval, power supply is in charge of the machine. In spite of the low rewinding speed (e.g., 20 to 30 meters per hour), similar stress to the pipe can occur. In addition, mechanical components of the machine (i.e., reel and gear) are subjected to abnormal stress and, in some cases, rollover prone conditions can arise due to unexpected lateral movements of the machine. Energy used for these operations is expected to vary with the length of unrolled pipe, pipe weight (e.g., whether empty or filled) and friction coefficient between pipe and surface during relative movement. In order to reduce the aforementioned problems and limitations, an innovative system named Protector was conceived by Irriland srl, an Italian manufacturer of reel machines, and developed with the support of the GESAAF Department of the University of Florence. During cart pulling for positioning at the field far end, the pipe unrolls from the reel machine, while the tape does the same from the cart reel and lays down on the ground, under the hose. During irrigation, both pipe and tape roll up in the respective reel. The result is that friction between soil and sliding pipe is replaced by friction between tape and sliding pipe, which is lower due to the characteristics of the tape. The length of the tape is at least equal to that of the irrigation pipe. Field tests, still in progress, aim to investigate and assess the potential advantages allowed by Protector, which in principle consists of a tape, about 60 cm wide, made of recycled plastic, rolled up in a small reel positioned in the travelling cart. Two prototypes, coupled to machines having different pipe lengths and diameters, have been used on Sugarbeet and Alfalfa in order to assess the influence of the tape on the traction force necessary for the movement of the travelling cart in different conditions (i.e., with and without Protector, whether pipe is filled or empty). According to results, traction force increases linearly and Protector tape is able to reduce dramatically (i.e., from about 30% onwards) the sliding friction occurring during pipe unrolling, regardless of crop type, pipe diameter and length. When filled of water, about 30% additional traction force has to be applied. Under test conditions, applied traction force to protected empty pipe does not exceed 1 ton/250 m of unrolled pipe in all cases. This condition can allow the use of lighter pipes (i.e., thinner thickness given the same outer diameter), so potential advantages, such as reduced energy use for water lifting and emission of Greenhouse Gases (GHG), reduced energy consumption and impact during PE pipe production, reduced monetary cost for the farmer due to non replacement of the standard pipe (e.g., working in protected sliding conditions), were assessed under irrigation scenario that is normal in sub humid Mediterranean climate (i.e., 210 mm seasonal irrigation depth). Results indicate that GHG emissions due to water lifting is reduced up to 25.5 %, while emissions during PE pipe production, assessed according to the Life Cycle Analisis (LCA), are reduced from 37% to 69% depending on whether pipe lifetime is equal to or shorter than that of the machine, respectively. Under the reasonable hypothesis of replacing the standard pipe (i.e., Protector is not used), total cost for the farmer and impact on climate increase by 48.7% and 39.6%, respectively, at the end of the economic lifetime of the machine. It should be noted that energy use for pumping is by far both the main source of GHG and cost for the farmer, and that the use of lighter pipes, allowed by Protector, can reduce dramatically both GHG emissions and pumping cost.

W-A-04: Irrigation infrastructure development (II)

Yasser Ali - Egypt's experience in biological weed control by grass carp, Centopharyngodon idella - Abstract Mechanical and chemical methods of aquatic weed control meet conventionally increasing objections on economic, environmental and human health grounds. An alternative approach is the use of the biological agent grass carp (Ctenopharyngodon idella Val.), a herbivorous fish. This biological method has mainly been used in Europe and the USA, but since 1976 Egypt has been investigating the potential of this approach for its waterways. Many aspects of the production and use of grass carp have been studied and evaluated. The long term experience of such biological control has shown that a stocked grass carp population not only provides effective weed control, but it also increases the protein production in Egyptian waterways substantially. If managed well, this production can provide continuous revenues that far outweigh the costs of weed control by other means. The necessary management techniques developed are mainly based on yearly restocking with grass carp and cooperation between waterways authorities and professional fishermen. The experience and lessons learned described in this paper will be of interest to many other countries.The objective of this research is to evaluate the results of applying biological weed control method by grass carp in Egypt at the reach between High Dam and Aswan Reservoir as well as a number of canals and drains. This verifies the application efficiency of in controlling weed infestation and reducing maintenance costs by comparing to mechanical control.

Sam Schaefer - Facility Improvements to Increase Conveyance and Recharge Capacity as a Regional Adaptive Strategy in Poso Creek Integrated Regional Water Management Plan Area, Kern County, CA - This paper describes facility improvements and management actions within a region that are being implemented by districts and growers as an adaptive strategy to increase conveyance and absorptive capacity of available surface water supplies during the wet years. Districts within the Poso Creek Integrated Regional Water Management Plan (IRWMP) area have added conveyance and groundwater recharge capacity over the past decade that were utilized during the wet year of 2017; spreading facilities constructed are both permanent and temporary as districts and growers have worked together to construct facilities that can absorb surface water supplies when they are available. The Poso Creek IRWMP area consists of seven agricultural water districts in the southern San Joaquin Valley with roughly 350,000 irrigated acres. The districts have surface water rights for delivery of local Kern River Water, State of California State Water Project (SWP) Water, and Federal Central Valley Project (CVP) supplies via Friant-Kern Canal and CVP-Delta supplies delivered via the California Aqueduct. The districts have implemented regional improvements to conveyance facilities since forming the IRWMP in 2007. Adaptive management actions are based on conjunctive management of surface and groundwater supplies to increase the absorptive capacity of surface water supplies; however, these regional improvements are limited in effectiveness given the various surface water storage and conveyance constraints experienced in the State of California. Regional conveyance constraints that affect the Poso Creek IRWMP area include loss of capacity in the Friant-Kern Canal and the California Aqueduct due to land subsidence that has occurred over time and exacerbated in the recent drought. The substantial loss of regional canal capacity is having an effect on the ability to move available surface supplies into groundwater recharge to replenish California groundwater aquifers, many of which had been greatly depleted by extended drought conditions from 2012 through 2016, and many that have experienced overdraft over the past 30 or more years. The wet period experienced in 2017 provided a real performance measure for adaptive strategies. Given conveyance constraints exist for delivering surface supplies into the region, the adaptive strategy being implemented adds regional conveyance and spreading facilities, which adds flexibility to absorb surface supplies as part of the extensive conjunctive management practiced in the area. In addition, development of regional conveyance recharge facilities is an adaptive strategy identified and practiced by the water district management professionals and growers to adapt to meet the Sustainable Groundwater Management Act (SGMA) requirements and climate change. The authors of this paper have worked on implementing collaborative projects within the Poso Creek IRWMP for more than a decade. Several papers related to construction of components within the Poso Creek IRWMP area have been presented at past USCID conferences.

Mona Liza Delos Reyes - Emerging design considerations for modernisation of national irrigation systems in the Philippines - The areas actually irrigated by the national irrigation systems (NIS) in the Philippines have been consistently lower than the developed irrigation service areas of the country. This gap between the irrigation service area and irrigated areas was attributed to issues with respect to the physical structures, system operation, water management, social and institutional aspects, and recently, to changes in rainfall patterns and vegetation of the river basins. A comprehensive study aimed at formulating a NIS modernisation strategy to address these issues was carried out by the authors with the end view of closing the gap and improving the irrigation system performance sustainably. Its research methodology was framed with deliberately selected assessment and characterization procedures, which were adaptively modified and integrated to critically analyze the consistency among the fundamentals of irrigation water delivery and to identify solutions for any incoherence that hinders the achievement of the desired irrigation service or performance. It employed rehabilitation impact assessment, logic design analysis, field measurements and pragmatic procedures of the Mapping System and Services for Canal Operation Techniques (MASSCOTE) in two sample national irrigation systems, the Balanac River Irrigation Systems (RIS) and the Sta. Maria RIS. The case study systems are situated in southern Luzon, the largest and most populous island of the country. They are both of gravity-type, run-of-the-river canal irrigation systems built and first operated in the 1960s and serving about 1,000 ha of rice areas. Balanac RIS has open and ungated offtakes, duckbill and long proportional weirs and a 30-km canal network, about 90% of which is concrete lined. Sta. Maria RIS has constant head orifice (CHO), gated offtakes, cross regulators with spindle-type vertical gates and has 80% of its 30-km canal network concrete lined. Both systems are ungauged, with natural waterways as drains. They were under irrigation management transfer (IMT) model 3, wherein the national irrigation agency managed the headwork while their respective irrigators associations were responsible for the management of the rest of the systems. The major irrigation issues in Balanac RIS and Sta. Maria RIS were inequitable water distribution and limited water supply, respectively. This paper presents new design considerations that emerged from the case studies. These include the following: i) conjunctive use of surface and groundwater for irrigation in downstream areas; ii) drainage water reuse; iii) downstream-to-upstream irrigation; iv) artesian well irrigation development; v) storage-type dam and main canal; vi) midstream dam; vii) minimum flow dependence of sub-secondary canals. The design factors were identified based on the results of analyses of the system field operations and local initiatives to cope with apparent design shortcomings in the face changing hydrological regimes and demands for irrigation service. The findings of the study showed that recaptured drainage water from upstream farms irrigated about 240 ha of Balanac RIS and Sta. Maria RIS service areas, while underlying shallow aquifers and nearby surface water bodies provided supplemental irrigation to about 170 ha of their service areas. The results implied that the early start of the irrigation season at the most downstream farms of Sta. Maria RIS helped moderate water scarcity and saved rice crops from submergence at tail-end farms during the dry and wet seasons, respectively. Also, they suggest that a midstream dam or intermediate mini-reservoir would address the flow dependence and waiting time for water supply of downstream farms in Balanac RIS, which has a long bifurcating canal hierarchy. Meanwhile, storage-type dams would be needed to have a more reliable irrigation supply as the existing run-of-the-river dams of the case study systems could not divert sufficient water, especially during the prolonged dry season. Water supply augmentation and management of water distribution were the two key strategies adopted in the case study systems to address their irrigation problems. The specific approaches to achieve them point towards possible modernisation solutions for the existing NIS and additional considerations in planning and designing new NIS.

Kazem Shahverdi - Fuzzy Sarsa Learning (FSL) algorithm convergence and generalization in small and large space problmes for water delivery in irrigation canals - Agricultural water management improvement is one of the main challenges for water researchers and engineers. Different optimization and artificial intelligence techniques have been used to develop operational instructions to improve agricultural water management. Regular artificial intelligence algorithms are using a supervisor to learn the pair of input-output (Structural Operation - Hydraulic status). Reinforcement Learning (RL) as a new learning algorithm has been developed based on the interaction between an action and an environment. Recently, a type of RL, named FSL (Fuzzy SARSA Learning) algorithm, has been developed and used in many fields of industry for large spaces problems. In this study the FSL has been developed to extract the operational instructions for water delivery problem in irrigation canals. In FSL process structural operations are simulated in hydraulic model of irrigation canal, and hydraulic status and water delivery is calculated. Based on the simulated outputs and desired hydraulic status, a reward is assigned to each operation. A series of the rewards are produced for a number of operations, and a Q-function is developed as a learning function. The developed Q-function would be the guideline for determining operations for other hydraulic situations without any further hydraulic simulations. The output of the FSL model is the learned Q-function and structures adjustment. The FSL has two main features which must be investigated, one is generalization, and another is convergence. The FSL uses a limited number of the inputs to extract the corresponding outputs and learns a Q-function as an online process. The generalization means that the FSL can predict the output of any input in the problem space using only the learned Q-function without any extra learning. In fact, the FSL learns online for some requests and predicts, the operational instructions of any possible request as an offline process. The FSL generalizes if it converges. The FSL convergence has been proved using mathematical relations in the robot control problems. It is necessary to investigate the convergence of FSL for hydraulic problems such as, water delivery and distribution in irrigation canals. The convergence and generalization features of FSL in irrigation canals are investigated in this paper. To investigate the FSL generalization and convergence features, the East Aghili canal is used which has 20 turnouts and 11 check structures. The distance between two successive check structures is defined as a block. The canal operation in all blocks should deliver flow with acceptable accuracy, while establishing water depth upstream of the check structures within the dead band. To investigate FSL generalization, 10 states are defined to learn a Q-function, named Q1, and 10 another states are defined to learn another Q-function, named Q2. Considering the defined states, the FSL is performed, and Q1 and Q2 functions are extracted separately. The FSL model is run to find the structures adjustment and related rewards using Q1-function and Q2-function separately. According to the authors experiences the FSL could generalize if the corresponding rewards difference is low and less than 15%. The lower the reward difference, the better the generalization is. The results showed the corresponding rewards of the Q1 and Q2 functions are close to each other; even the reward difference are zero in some states. The maximum reward difference was 11.1%. The FSL was converged in all blocks, and the rewards of the final actions are close to the desired value. This shows that the FSL algorithm could be used as an efficient tool for development of operational instructions in irrigation canals with sufficient confidence.

Mykhailo Romashchenko - Strategy of irrigation and drainage rehabilitation and development in Ukraine up to 2030 - Most of the territory of Ukraine is characterized by various natural and climatic conditions that are quite favorable for agrarian production. According to FAO estimates, the agro-resource potential of our country makes it possible to produce agricultural products sufficient to provide food for about 500 million people. However, suboptimal conditions of natural moisture availability in 2/3 territory of the country restrict the sustainable development of agriculture. Against the backdrop of global climate change which for Ukraine is characterized by the increase in aridity, manifestation of desertification processes as well as an increase in the deficit of natural moisture available, the role of irrigation and drainage rises considerably. For today almost 60% of agricultural land suffer from the lack of natural water supply ranging from 150 to 500 mm/year. In the south of the country, i.e. Kherson, Zaporizhzhia, Mykolaiv and Odesa regions, the sustainable crop production is impossible without irrigation applying. And in the northwestern region, in the humid zone, to ensure a deficit-free water balance some extra water supply is also needed for the cost-effective agriculture production during a growing season, especially in the second half of it. On the other hand, constructed in the past a powerful water supply ameliorative complex provided irrigation on the area of 2.65 million hectares and drainage on 3.3 million hectares is used extremely insufficiently as of today. In fact, less than 500 thousand hectares were actually irrigated in 2017, and bilateral water regulation on drainage systems was carried out on the area of about 250 thousand hectares that accounts for 20 % of existing irrigated areas and less than 10 % of existing area of drainage. It is worthy to note that the capacity of existing ameliorative infrastructure is still sufficient for providing irrigation in the area about 1.8 million hectares and water regulation - more than 2.0 million hectares. Unsatisfactory state of the use of irrigation and drainage potential is caused by the disinvestment to engineering infrastructure, non-completion of reforms in economic sector and land reforms, imperfection of the mechanisms of state support and existing legislation, the inefficiency of the management model in the amelioration field and its non-conformity to new market conditions. Having such situation with the use of ameliorative facilities there is a threat of their total destroy and destruction. In view of the demand of increasing the agricultural production in the conditions of climate change, the problem of efficient use of the existing potential of irrigation and drainage and its further development is a prerequisite for overcoming the crisis situation, minimizing the negative impact of climate change and adapting the agrarian sector of the economy to new market conditions. The development of a Strategy for the restoration and development of irrigation and drainage for the period up to 2030 was the first step towards the fulfilling this task. The draft paper based on the main international framework principles was prepared jointly with a team of the World Bank experts, the Food and Agriculture Organization of the United Nations in cooperation with the Coordination Council established under the Cabinet of Ministers of Ukraine. The strategy is based on the scientific and conceptual foundations of amelioration rehabilitation and development, established in the Institute of Water Problems and Land Reclamation of the National Academy of Agrarian Sciences in Ukraine. The general objective of the Draft Strategy is to establish an efficient irrigation and drainage service sector managed by water users that would ensure the sustainable agriculture in climate change and contribute to solving the strategic task of agricultural development in Ukraine to achieve the position of a competitive global player in food production. To achieve this goal, five major strategic objectives were identified, which include legal and investment reforms performing; stimulating investment in restoration, modernization and development of existing irrigation and drainage infrastructure; reforming and implementing sector management policies for the benefit of all stakeholders; development of the capacity of associated research, design, operation, training organizations; compliance with the priority of environmental protection, including preservation and reproduction of soil fertility, protection of land and settlements against harmful effects of water, improving and maintaining a good state of water resources. The Draft Strategy includes the conceptual provisions for the formulation and implementation of the state policy aimed at establishing legal, organizational, regulatory, methodological, financial and economic mechanisms of irrigation and drainage restoration and ensuring their sustainable development based on the implementation of the principles of integrated water resources management and decentralization of irrigation and drainage infrastructure operation through transferring the on-farm irrigation networks to water user organizations. The program for sector reforming and financial support mechanisms for performing restoration measures were formulated, as well as an initial action plan and a phased timetable for the implementation of the reforms under the Strategy were proposed. The main provisions and principles of this document are in line with the Sustainable Development Strategy œUkraine 2020 • , the only comprehensive Strategy for the Development of Agriculture and Rural Areas for 2015-2020 (draft), the Basic Principles of the State Environmental Policy of Ukraine for the period up to 2020, the Objectives of the Sustainable Development on the period up to 2030, the EU-Ukraine Association Agreement, the European Atomic Energy Community, the State Strategy for Regional Development , Water Framework Directive 2000/60/EC of the European Parliament and of the Council on the establishment of the Community action in the field of water policy, Directive 2007/60/EC of the European Parliament and of the Council on the assessment and management of flood risks. The implementation of the Strategy will require the introduction of amendments and additions to the existing legislation and development and adoption of new laws and other regulatory acts. Conclusions. The implementation of the developed Draft Strategy will ensure a highly efficient and ecologically safe use of reclaimed land, sustainable development of irrigation and drainage facilities, adaptation of the agrarian sector of the economy to global climate change, establish an effective water management system for transformation of Ukraine into a reliable and competitive food producer in the world markets. It will also improve the socio-economic, ecological and living conditions and the development of rural areas.

W-B-04: Climate smart agriculture and innovative technologies for enhancing water use efficiency (IV)

Dr Susan O'Shaugnessy - Variable Rate Irrigation Systems with Sensor-feedback (Solicited) - Introduction. Climatic variability, especially unpredictable patterns of intraseasonal and interannual precipitation significantly impact irrigation management and water policies. Many farmers who have traditionally relied on rainfed crop production now use supplemental irrigation, while farmers in water-limited regions are continuously challenged to improve irrigation efficiencies and conserve water. Both scenarios require attentiveness to timely water applications and appropriate application amounts. Site-specific irrigation management (SSIM) or applying the right amount of water when needed and where needed is critical to optimizing yields and water use efficiency (WUE), but requires intensive time commitment for large-sized fields. In the U.S., center pivot sprinklers irrigate more than 57% of irrigated land (USDA-NASS, 2013). Many of these sprinkler systems have speed control capabilities allowing for variable water applications in the direction of sprinkler movement. Even greater flexibility is facilitated by zone control VRI systems, which are available commercially and usually compatible across manufacturers. However, optimal irrigation management with VRI systems, either maximizing yields or crop water use efficiency, requires the integration of plant and soil water sensing feedback to detect spatiotemporal plant water status across a field. Materials and Methods: In 2017, a smart irrigation system, patented as the Irrigation Scheduling Supervisory Control and Data Acquisition (ISSCADA) system (Evett et al., 2014), was used for SSIM of corn (Zea Mays L., cv. Dupont Pioneer P1151AM). One-half of the field was irrigated using speed control VRI and the other half was irrigated using zone control VRI. The core elements of the ISSCADA system were embodied in a client-server software that resided on an embedded computer located at the pivot point. The computer collected, stored and processed data from wireless weather, canopy temperature and soil water sensor networks. Decision support in the form of dynamic and interactive prescription maps were built automatically (after midnight) for the area of the field that the sprinkler traveled across during daylight hours. Wireless infrared thermometers (SAP-IP IRTs, Dynamax, Houston, TX; using the Zigbee communication protocol IEEE 802.15.4) were mounted on the sprinkler pipeline on masts forward of the drop hoses to monitor a dry canopy temperature. Two IRTs were positioned on the pipeline at the edge of each concentric management zone, aimed towards the center of the zone at an oblique angle relative to the vertical mast on which the sensor was mounted and rotated inwards from the direction of travel at a 45Â° angle. Weather parameters (air temperature, relative humidity, solar irradiance and windspeed) were sampled every 5 s and averaged and stored every one minute at a nearby weather station (Campbell Scientific, Logan, Utah). Irrigation timing and amounts were determined by a preestablished thermal stress index, the integrated crop water stress index (iCWSI) (OShaughnessy et al., 2015), which is based on the theoretical CWSI developed by Jackson et al. (1981). Calculated iCWSI values for each management zone were determined from one-time-of-day canopy temperature measurements using a scaling algorithm (Peters and Evett, 2004) and compared with the preestablished thresholds. In-situ time-domain reflectometry (TDR) soil water sensing stations (TDR-315Ls, Acclima, Meridian, Idaho) were installed in four plots managed by VRI speed control. Each station contained three TDRs installed horizontally in the plant row at depths of 10, 35 and 45 cm below the soil. Soil water sensors were used to close the plant feedback loop and prevent over- and under-irrigation of plots. Plots managed by VRI zone control in the northwest half of the field, received irrigation treatment levels of 80%, 50% and 30% (I80, I50 and I30) replenishment of soil water depletion in the top 1.5 m to field capacity as determined by weekly neutron probe readings or by plant feedback using the iCWSI thresholds and corresponding irrigation amounts (Table 1). Grain yields and water use efficiencies were compared between plots managed with plant feedback and the combination of plant feedback and soil water sensing feedback; and between VRI zone control plots managed with plant feedback and VRI zone control plots managed with the neutron probe. Preliminary Findings: Mean adjusted grain yields and WUE under speed control VRI were similar between plots managed with plant feedback plots and plots managed with plant and soil water sensing feedback. Under zone control VRI, mean dry grain yield and WUE for treatment plots at the I80 and I50 treatment levels were similar, while for the I30 level, WUE were similar, but grain yields were significantly greater for plots managed with the plant feedback method. Conclusion: Variable rate irrigation systems (speed and zone control) integrated with ground-based plant sensor network systems provide adequate information to facilitate the practice of site-specific irrigation management for corn grown in a semi-arid region. References Evett, S. R., S.A. O'Shaughnessy and R. T. Peters. (2014). Patent application serial No. 13/403,091 Entitled "Irrigation Scheduling and Supervisory Control and Data Acquisition System for Moving and Static Irrigation Systems". Patent allowed August 29, 2014. Jackson, R.D., Idso, S.B., Reginato, R.J., Pinter, P.J., 1981. Canopy temperature as a crop water stress indicator. Water Resour. Res. 17, 1133“1138. OShaughnessy, S.A., Evett, S.R., Colaizzi, P.D. 2015. 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Dr Ragab Ragab - New technologies for more accurate estimation of crop water requirement without the crop coefficient Kc (Solicited) - The current methods of calculating crop irrigation water requirements use equations fed by meteorological data such as temperature, wind speed, relative humidity etc. However these equations calculate the atmospheric not the crop demand for water. The results are values that represent the maximum / potential evaporation, not the actual. An accurate crop water requirement should be based on crop and soil demand, not on atmospheric demand for water. Modern technologies such as the use of scintillometers or the eddy covariance technique measure actual evaporation that represent the real crop need for water. These instruments were installed at an experimental farm near Bologna in Italy to measure actual evapotranspiration / crop water requirement during two cropping seasons (2014 and 2015). The results showed significant differences when compared with the present practice. On average the actual crop water requirement based on the modern technologies could save at least 50% of irrigation water for this region. Another benefit is that these technologies do not need what is called the crop coefficient which can be difficult to obtain for many irrigation practitioners. In addition, a new technology, the Cosmic-Ray Soil Moisture Observation System (COSMOS), to determine the crop water requirement through real-time continuous soil moisture content and deficit has been tested. This method can sense soil moisture for an area of 300-700 radius. A COSMOS probe over a mixed crops area during the same cropping seasons has been installed. The results showed that soil moisture values obtained by COSMOS were comparable with those obtained for the top 0-60cm layer by sensors, soil cores, Profile probes and with values simulated by the SALTMED model. This indicates that the COSMOS probes effective depth is within the top 0-60cm. Knowing that almost 80% of the crop root systems is accommodated within the top 0-60cm, the COSMOS measurement could be useful for monitoring the soil water status and deficit in the root zone in irrigated agriculture. The COSMOS technology is one step in the right direction as it provides continuous, integrated, area-based values and solves the problem of spatial variability often found in point measurements. This method could also be used to determine the soil moisture deficit, hence determine when and how much to irrigate. It could be made operational for irrigation managers to determine when and how much to irrigate to avoid harmful water stress. The results of this study have worldwide implications as globally 70% of freshwater used for agriculture. Doubling food production by 2050, when we will need to feed 9 billion people, requires efficient water use to achieve this aim from the same amount of water. Accurate estimate of crop irrigation requirement based on actual evapotranspiration is the way forward. 1Centre for Ecology and Hydrology, CEH " Wallingford, UK 2Consorzio di Bonifica di secondo grado per il Canale Emiliano Romagnolo (CER), Bologna, Italy

Dr Willemijn Appels - Exploring management of subsurface drip irrigation technology in southern Alberta: indoor insights and field findings - Subsurface drip irrigation (SDI) is the most water efficient irrigation technology available. It delivers water directly into the root zone without interception losses and with minimal evaporation losses. SDI systems are not easy (and expensive) to install and have long been considered suitable for perennial, high value crops only. However, the ability to irrigate irregularly shaped fields, options for fertigation and fully automated water management have prompted interest in SDI for a suite of field and specialty crops. In southern Alberta Canada, these include mint, seed canola, and dry beans. While the foundations of flow around emitters are well understood, the influence of soil heterogeneity and erratic weather patterns on management decisions are not fully quantified and often require local solutions. The exceptionally warm and dry summer of 2017 pushed SDI systems in southern Alberta to their limits. Observed water management issues included problems with uniformity of applications, but also leaching of water from the root zone. Lethbridge College and Southern Irrigation created a large-scale laboratory setup to evaluate and improve water management of SDI systems on a scale that resembles field conditions and can be operated outside the normal growing season. Three wooden bins (6x3x1.2 m) were built and filled with a clay, loam, and sandy soil respectively. In each bin, four individually controlled SDI systems (of varying line depth and emitter spacing) were installed and an alfalfa crop was seeded. We monitor soil moisture dynamics around the SDI drip lines during 16 irrigation scheduling experiments. A monitoring campaign was set up in SDI fields with similar soil types to verify the findings from the indoor experiments under real weather conditions. Here, we present preliminary results from these experiments and discuss their implications for SDI management. Options for future projects in the large-scale soil irrigation facility will be presented as well.

Dr Ingrid Wesström - Can you increase the crop yield with just a few irrigation events? Proper water and nutrient management are prerequisites for high yields. In addition to the already high crop production requirements, new even higher demands are expected in the near future such as more efficient utilization of water resources, less nutrient losses, higher yield quality and economical optimization. This means that further improvements with regard to efficient use of different inputs are necessary. The overall objective of this study was to develop recommendations aimed to optimize supplementary irrigation schedules for cereals. Strategies for supplementary irrigation adapted to the soil's water retention capacity were evaluated in order to prevent drought stress by taking into account the water requirements at different crop development stages and climate conditions. By applying irrigation during critical crop development stages, yields can be increased. This kind of information is of great importance when farmers are to weigh the pros and cons of irrigation. The study included field trials at three different locations in Southern Sweden. Measurement of the soil water content was performed once per week in each experimental plot with a Delta-T probe at six depths (0-10 cm; 10-20 cm; 20-40 cm; 40-60 cm; 60-80; 80-100 cm). Root depth was measured twice in each plot. The yield was measured in each plot in all blocks. Farming operations such as fertilization, planting and chemical control were recorded. Observations of development stages were carried out four times and shoot and ear counts one time per season. Grading was made of plant diseases, nutrient deficiency, weed occurrence, straw strength and green shoots at harvest. The irrigation demand was calculated from a water balance where the loss of water was the difference between precipitation and evapotranspiration. The climatic data was measured at each experimental site. The water requirement of crops differ during the growing season, depending on the stage of development and the type of crop. By using a crop coefficient in the water balance calculation, the growth stage of the crop was taken into account. One field trial was carried at HelgegÃ¥rden, SkepparslÃ¶v on a loamy sand with winter wheat (Mariboss). The experiment was fertilized with 170 kg of N ha-1. A second trial was established at Torslunda, FÃ¤rjestaden on a loamy sand, also with winter wheat (Mariboss). The experiment was fertilized with 142 kg N ha-1. The third trial was carried out at Stora Tollby, Gotland on a clayey loam where Durum wheat (Rosadur) was planted. The experiment was fertilized with 266 kg N ha-1. The trials consisted of four randomized blocks with four irrigation treatments. In total, the trial had 16 experimental plots. All treatments were randomized within each block. Irrigation was carried out with boom irrigation. The treatments represented different levels of water stress; A. No irrigation, control; B. Optimal irrigation, when 40% of the available water has been consumed; C. Early irrigation, 1-3 times, if needed, in case of poor emergence, otherwise from tillering to booting with 20-30 mm per irrigation; D. Late irrigation, 1-3 times, from booting to flowering and after flowering to ripening, with 20-30 mm per irrigation. The results from the growing season 2017 are shown in Tables 1 to 3 (not included in this summary) When precipitation deficit occurred during early summer, the treatment with an early irrigation had more shoots and ears per m2 compared to no irrigation treatments. In all experiments, irrigated treatments had a higher crop yields compared no irrigation treatments. At HelgegÃ¥rden, the optimal irrigated treatment resulted in a yield increase of 7.6 kg per mm irrigation and the early irrigation treatment in a yield increase of 7.1 kg per mm irrigation. Precipitation surplus in the mid-season resulted in treatments B and C being the same irrigated twice and treatments A and D being not irrigated. At Torslunda, the optimal irrigated treatment had a yield increase of 23.0 kg per mm irrigation. The yield increase for treatment C and D was 30.0 and 29.1 kg per mm irrigation, respectively. At Stentollby, the optimal irrigated treatment had a yield increase of 5.4 kg per mm irrigation and the yield increase of early and late irrigation were 26.5 and 0.9 kg per mm irrigation, respectively. The results showed that irrigation at precipitation deficit in early summer season is an important prerequisite for a high yield and provided the best return for irrigation.