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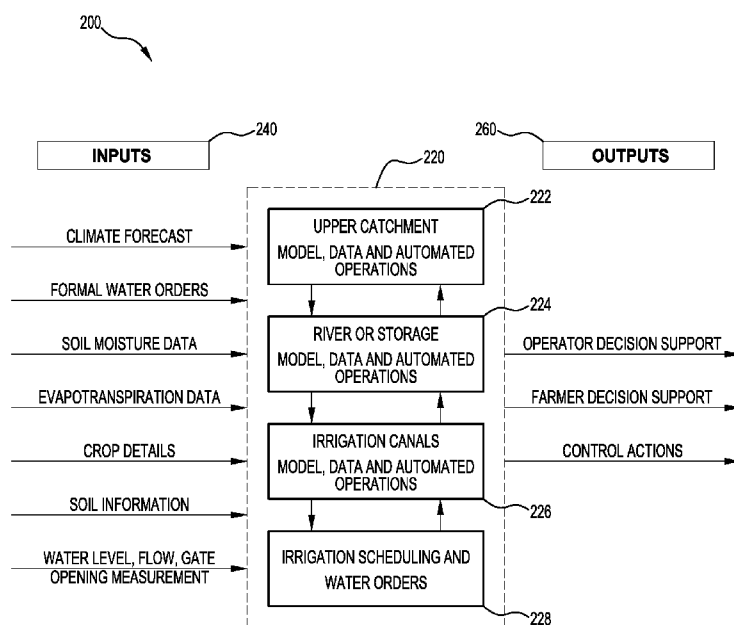


Figure 2

(57) Abstract: A method of spatially deriving the soil moisture at a selected location within an irrigation district to be irrigated, said method including the steps of using system identification techniques to produce an algorithm for evapotranspiration based on a predetermined selection from the following measured parameters: solar radiation spectrum, wind speed, temperature, humidity, crop factor, soil type, barometric pressure, irrigation historical data, and energy measurement from solar panels at each of a plurality of representative locations; calibrating said algorithm by direct measurement of the moisture in the soil at each of said representative locations by respective soil moisture sensors; and using measured parameters of rainfall, soil type, irrigation historical data and crop factor with said algorithm to derive or interpolate soil moisture at said selected location within said irrigation district.



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METHOD AND SYSTEM FOR WATER DISTRIBUTION

AND SOIL MOISTURE DETERMINATION

[0001] The present application claims priority from Australian Provisional Patent Application No. 2017903250 filed 14th August 2017 and Australian Provisional Patent Application No.2018901564 filed 8th May 2018, the entire contents of which are incorporated herein by reference.

FIELD

[0002] Some aspects of the present invention relate to methods and systems for irrigation and/or otherwise distributing water. Some of these methods and systems rely on estimates of soil moisture level. Other aspects of the invention relate to estimating soil moisture. Some of these other aspects rely on an indication of solar intensity. Further aspects of the invention relate to obtaining an indication of solar intensity.

[0003] The invention is described herein with reference to irrigation by way of example only. Other examples may be applied in other contexts, e.g. the disclosed water distribution methods may be applied to flood management. Likewise estimates of soil moisture and solar intensity may be useful for purposes other than water distribution.

BACKGROUND

[0004] Irrigation is typically the largest consumer of land based fresh water. It also contributes to largest amount of water wastage. Existing irrigation systems typically have a water delivery efficiency in the range of 35% to 50%. That is, in delivering water from a catchment, only less than half the volume of water delivered will reach its final destination.

[0005] In a typical irrigation system, around 30% of water is lost from a dam to a canal gate. The losses may be due to operating spills, poor measurement, leaks, seepage, and evaporation. From the gate to the farm, there is a further loss of 50% of water. The losses at this stage may be due to poor service, slow delivery, varying

flows, and poor control. There are further water losses from the farm to the plants/crops, which may be due to imprecise timing of water delivery and lack of crop measurements (to determine whether or not a crop needs water). Typically, only 35% of water diverted from the catchment will reach the crop.

[0006] In addition, existing irrigation systems do not achieve consistent flow rates to the farms. Existing methods for calculating evapotranspiration (ET) make use of satellite data. The ET data obtained from these existing methods is however not accurate because of the separation between the field and the satellite.

[0007] Embodiments of the present invention seek to provide improvements in and for water distribution; soil moisture, ET estimation and/or solar intensity indication; or to at least provide the public with a useful choice.

[0008] It is not admitted that any of the information in this patent specification is common general knowledge, or that the person skilled in the art could be reasonably expected to ascertain or understand it, regard it as relevant, or combine it in any way before the priority date.

SUMMARY

[0009] According to an aspect, the present invention provides a method of spatially deriving the soil moisture at a selected location within an irrigation district to be irrigated, said method including the steps of:

using system identification techniques to produce an algorithm for evapotranspiration based on a predetermined selection from the following measured parameters: solar radiation spectrum, wind speed, temperature, humidity, crop factor, soil type, barometric pressure, irrigation historical data, and energy measurement from solar panels at each of a plurality of representative locations;

calibrating said algorithm by direct measurement of the moisture in the soil at each of said representative locations by respective soil moisture sensors; and

using measured parameters of rainfall, soil type, irrigation historical data and crop factor with said algorithm to derive or interpolate soil moisture at said selected location within said irrigation district.

[0010] In an embodiment said soil type is determined by ground penetrating radar to develop a relationship between the radar signal and the water holding capacity of the soil.

[0011] In an embodiment said irrigation historical data is based on the time and volume of the irrigation to provide saturation data on said soil moisture and/or said solar radiation spectrum includes visible light and near-infrared light.

[0012] In a further embodiment there is further included an irrigation management system to irrigate predetermined areas of said irrigation district, said irrigation management system monitoring: said derived or interpolated soil moisture for said predetermined areas; availability of irrigation water to said predetermined areas; and requests for timed irrigation from end users for said predetermined areas; and allows requested irrigation to occur for said predetermined areas based on said monitoring.

[0013] In yet a further embodiment, said irrigation management system monitors an irrigation conveyance network from catchments to supply water to areas to be irrigated under demand by said end users. The irrigation management system monitors said soil moisture at said plurality of representative locations and monitors at least one or more of climate forecast, water orders from end users, crop details, water levels, and flow gate opening measurements of said irrigation district.

[0014] According to another aspect, the present invention provides a soil moisture determination system to spatially derive the soil moisture at a selected location within an irrigation district to be irrigated, said system including a networked computer system connected to a plurality of weather stations within said irrigation district to measure a selection from: solar radiation spectrum, wind speed, rainfall, temperature, humidity, barometric pressure, and energy measurement from solar panels at each of a plurality of representative locations, said networked computer system having data access to crop factor, soil type, and irrigation historical data at said representative locations, said networked computer system using system identification techniques to produce an algorithm for evapotranspiration based on a predetermined selection from the weather station measurements and the data access to crop factor, soil type, and irrigation historical data at said representative locations ; said networked computer system calibrating said algorithm by direct measurement of the moisture in the soil at each of said

representative locations by respective soil moisture sensors; and using measured parameters of rainfall, soil type, irrigation historical data and crop factor with said algorithm to derive or interpolate soil moisture at said selected location within said irrigation district.

[0015] In an embodiment, said soil type is determined by ground penetrating radar to develop a relationship between the radar signal and the water holding capacity of the soil. The irrigation historical data is based on the time and volume of the irrigation to provide saturation data on said soil moisture.

[0016] In a further embodiment, said solar radiation spectrum includes visible light and near-infrared light.

[0017] In yet another aspect of the invention there is provided an irrigation management system to irrigate predetermined areas of an irrigation district including the soil moisture determination system as previously defined, said irrigation management system monitoring: said derived or interpolated soil moisture for said predetermined areas; availability of irrigation water to said predetermined areas; and requests for timed irrigation from end users for said predetermined areas; and allows requested irrigation to occur for said predetermined areas based on said monitoring.

[0018] In an embodiment, said irrigation management system monitors an irrigation conveyance network from catchments to supply water to areas to be irrigated under demand by said end users. The irrigation management system monitors said soil moisture at said plurality of representative locations and monitors at least one or more of climate forecast, water orders from end users, crop details, water levels, and flow gate opening measurements of said irrigation district.

[0019] In yet a further embodiment said weather stations are included with a plurality of said flow gates.

[0020] According to an aspect, the present invention provides a method of controlling a water distribution system, the system having at least one at-least-predominantly-free- surface flow-path from which water is deliverable to soil; and the method including

controlling the system based on at least

a moisture level of the soil; and

at least one supply indicator, wherein the at least one supply indicator being an indicator of at least one of:

at least one volume of water in the system;

an inflow of water to the system; and

a future inflow of water to the system.

[0021] In an embodiment, the controlling includes causing water to be delivered to the soil to utilize a capacity of the soil to accept water at least one of a) in response to a surplus of water; and b) in anticipation of a surplus of water. The system preferably includes a system portion from which the water is so delivered. The method preferably includes reducing a volume of water in the system portion to make storage capacity within the system portion available to capture surplus water.

[0022] According to another aspect, the present invention provides a method of controlling a water distribution system, the system having at least one at-least-predominantly-free-surface flow-path; and the method including delivering water from the flow-path in accordance with a delivery schedule; receiving at least one supply indicator being an indicator of at least one of

at least one volume of water in the system;

an inflow of water to the system; and

a future inflow of water to the system; and

at least influencing the delivery schedule based on the at least one supply indicator.

[0023] In an embodiment, the flow path is at least 100km long.

[0024] In an embodiment, the at least one supply indicator is an indicator of at least one of

at least one volume of water in the system upstream of the flow path;

an inflow of water to the system upstream of the flow path; and

a future inflow of water to the system upstream of the flow path.

[0025] In an embodiment, the controlling includes controlling a supply of water to the flow path.

[0026] According to another aspect, the present invention provides a method including utilizing as an indication of solar intensity an output of at least one photovoltaic powering a device.

[0027] In an embodiment, the device is an electromechanical device. The device may be one or more of a water control barrier, a pump, a flow meter and a water level sensor for example.

[0028] According to yet another aspect, the present invention provides a method of estimating at least one of a moisture level of soil and an evapotranspiration from the soil, the method including applying logic to an output of at least one photovoltaic powering a device.

[0029] In an embodiment, the device is an electromechanical device. The device may be one or more of a water control barrier, a pump, a flow meter and a water level sensor for example.

[0030] According to yet another aspect, the present invention provides a method, of estimating a spatially-variable estimate of soil moisture level across an agricultural area, including applying logic to data indicative of at least

air temperature;

rainfall;

wind speed;

relative humidity;

solar intensity; and

one inherent characteristic of the soil.

[0031] In an embodiment, the data is indicative of an irrigation history associated with the agricultural area.

[0032] In an embodiment, the data is indicative of air temperature at at least two points at least proximal the agricultural area.

[0033] In an embodiment, the data is indicative of rainfall at at least two points at least proximal the agricultural area.

[0034] In an embodiment, the data is indicative of wind speed at at least two points at least proximal the agricultural area.

[0035] In an embodiment, the data is indicative of relative humidity at at least two points at least proximal the agricultural area.

[0036] In an embodiment, the data is indicative of an energy density for visible light.

[0037] In an embodiment, the data is indicative of an energy density for near-infrared light.

[0038] In an embodiment, the data is indicative of the at least one inherent characteristic of the soil at at least two points at least proximal the agricultural area.

[0039] In an embodiment, the data includes an output from at least one soil-moisture sensor at least proximal the agricultural area.

[0040] According to another aspect, the present invention provides a method of estimating a spatially-variable estimate of soil moisture level across an agricultural area, the method including applying logic to data indicative of at least

an output from at least one soil-moisture sensor at least proximal the agricultural area; and

spatially-variable satellite data.

[0041] In an embodiment, the data is indicative of an energy density for visible light.

[0042] In an embodiment, the data is indicative of an energy density for near-infrared light.

[0043] In an embodiment, the method includes applying logic to an output of at least one photovoltaic powering a device. The device is preferably an electromechanical device. The device may be one or more of a water control barrier, a pump, a flow meter and a water level sensor for example.

[0044] In an embodiment, the applying logic is applying a model having parameters adjusted to suit the agricultural area.

[0045] In an embodiment, the applying logic is applying a model derived from system identification.

BRIEF DESCRIPTION OF DRAWINGS

[0046] An embodiment of the apparatus will now be described by way of example only with reference to the accompanying drawings in which:

FIGURE 1 shows a typical prior art water distribution or irrigation system in a simplified pictorial representation;

FIGURE 2 shows a block diagram of an integrated catchment management system of the present invention;

FIGURE 3 shows a graph of soil moisture against time in a sample timeline;

FIGURE 4 shows an enlarged view of a modified gate or regulator described with reference to FIGURE 1;

FIGURE 5 shows an embodiment of a water distribution or irrigation system in a simplified pictorial representation; and

FIGURE 6 shows an automated supply process for irrigated water supply.

DESCRIPTION OF EMBODIMENTS

[0047] The preferred embodiments relate to a water distribution system (or irrigation conveyance network) using spatially very large networks of open channel

systems for supplying water. Apart from irrigation, the water distribution system may be utilized for industrial applications, and for the urban sector, for example. These conveyance systems largely operate under gravity in flat terrain and, as such, transport the water in a relatively slow way (compared to the near instantaneous response of a pressurised pipeline).

[0048] In the context of a river (or other at-least-predominantly-free-surface flow path) that is 500 km long, it can take days for an upstream influx (e.g. storm event) to propagate and result in higher water levels downstream. According to various existing methods, the propagating surplus can exceed the available freeboard resulting in overflow and wastage. It can also pass closed soil-supplying water-exits or gates en-route to the sea whereat it is also wasted.

[0049] The system is configured to avoid such wastage. By opening downstream soil- supplying water-exits or gates in anticipation of such a surplus the water levels within downstream portions of the flow path (from which the soil-supplying exits or gates convey water) can be lowered to make downstream freeboard available to capture the surplus.

[0050] Opening the exits or gates in anticipation of surplus effectively utilises the storage capacity of the soil. By also taking account the of the soil's available storage capacity, an optimal compromise between capturing surplus and overwatering can be achieved. The 'soil's available storage capacity' and similar terminology is used here as a reference to the difference between the soil's storage capacity (an inherent characteristic of the soil) and the soil's moisture level; that is as a reference to how much additional water the soil can store before being saturated. Likewise, a cost function associated with crop's need or tolerance for a water may be considered.

[0051] The water level (e.g. set point) in an upstream portion of the flow path may also be lowered in anticipation of an influx, e.g. in response to rain forecast in the catchment area or in response to temperature forecasts foreshadowing an influx of melt water.

[0052] FIGURE 1 is an extremely simplified pictorial representation of a water distribution system or irrigation conveyance network 100 that includes an upper

catchment or dam 120 fed by rivers or creeks (not shown); natural carriers (e.g. rivers) 130 and canal pools 140; canals 160 that offtake from these natural carriers 130 and/or canal pools 140; and channels 170 for delivering water to the crops 190 on farms 180.

[0053] The system 100 distributes water to the crops 190 and farms 180 (e.g. in response to water orders and/or as part of a delivery schedule). Water is sequentially supplied from the upper catchment 120 through the rivers 130 and canal pools 140 and canals 160 to the farms 180. Water is delivered to the crops 190 and farms 180 based on one or more of a customer demand, an irrigation schedule, and the supply of water available in the distribution network 100.

[0054] Water flow is controlled by gates or regulators 132, typically, but not limited to, overshot gates. Examples of such gates or regulators 132 are shown in the Applicant's CONTROL GATES of PCT Application No. PCT/AU2001/001036 (published as WO2002/016698, the contents of which publication are incorporated herein by reference). The control of water in the rivers 130 and canal pools 140 can be regulated by a plurality of gates or regulators 132 as shown in FIGURE 1 in view of the output therefrom. The Applicant's FLUID REGULATION of PCT Application No. PCT/AU2002/000230 (published as WO 2002/071163 A1, the contents of which publication are incorporated herein by reference) describe methods and systems for providing decision support for water delivery or the actual physical water delivery from the basin to the crops.

[0055] Each gate or regulator 132 is driven by an electric motor integrated into the structure thereof and powered by a rechargeable battery coupled to a solar cell 134 located on a pedestal 136. The pedestals 136 contain the required electronics and communication systems to enable each gate or regulator 132 to operate and data to be collected on the gate opening position and volume of water flowing through the gates or regulators 132. Data can be received and transmitted wirelessly using aerials 138 through radio or another telecommunication protocol to form a network with a remote computer system.

[0056] The water distribution system 100 provides an at least predominantly-free-surface flow path between the storage of the catchment 120 and the canals 160. As the terminology and similar technology are used herein:

- open irrigation channels and/or rivers are examples of free-surface flow paths; and
- a long open irrigation channel broken by a short piped-section under a roadway is an example of a predominantly-free-surface flow path.

[0057] Referring to FIGURE 2, an integrated catchment management system 200 is provided. The integrated catchment management system 200 accounts for the spatial and temporal characteristics associated with the water distribution system 100 in order to match the supply in the water distribution system to the demand at the farm/crops 180. The integrated catchment management system 200 provides the ability to forecast and pre-empt both demand and supply conditions in order to provide better operational outcomes such as delivering water in a timely manner as required by the crop, with no (or minimal) water loss in the delivery. In addition, the integrated catchment management system considers (and takes advantage of) the supply of water when it is available. By matching the supply with the demand, the integrated catchment management system is able to reduce the occurrence of oversupply (wastage) of water or undersupply of water to the users.

[0058] The integrated catchment management system 200 includes a control arrangement, such as one or more computer processors, for receiving and processing information relating to the water distribution system 100. The one or more processors of the water distribution system are additionally configured to control the operation of the water distribution system or provide a report to an operator/farmer. The one or more processors may additionally implement learning algorithms and automation for managing the water distribution system. The integrated catchment management system is additionally provided with a communication module for communicating with the sensors and actuators distributed across the water distribution system 100. The communication module preferably supports wireless communication such as via radio transmission, Wi-Fi, Bluetooth, and/or any other IEEE 802.11 standard of communication.

[0059] Using data and models to represent the tiers in the demand-side and supply-side in the water distribution system, the integrated catchment management system 200 seeks to match the demand to the supply. By modelling and analysing

each different tier of the water distribution system, the system 200 is able to forecast supply and demand conditions at either end of the water distribution system to provide optimal decisions and outcomes in meeting the operational objectives. Thereby, the integrated catchment management system 200 minimises the risk of oversupply or undersupply of water to the crops 190 and farms 180.

[0060] The integrated catchment management interconnects all the aspects and stakeholders from a crop root level to a broader basin level that uses real-time (e.g. at least daily or at least hourly) measurements and the real-time interflow of information and provides decision support for irrigation district and farmers and wherever there is infrastructure. In addition, the integrated catchment management is able to take autonomous control actions in order to match the supply to the demand.

[0061] The integrated catchment management 200 provides a water distribution model 220 consisting of the following sub-models to represent the different tiers of the water distribution system:

- model 222 for the upper catchment 120;
- model 224 for the natural carriers (e.g. rivers) 130 and storages 140;
- model 226 for the irrigation canals 160 and channels 170 that offtake from these natural carriers/storages.

[0062] The water distribution model 220 additionally includes delivery schedule 228 relating to irrigation scheduling and water orders that are placed against the crops/farms. The integrated catchment management system 200 may influence the delivery schedule by prompting (or otherwise providing decision support to) farmers (or other water recipients). Alternatively, the schedule may be implemented by adjusting a water pricing model. Other variants of the integrated catchment management system 200 may simply automatically vary delivery times.

[0063] The integrated catchment management system 200 spans from catchment to crops/farms and considers spatial and temporal changes along the flow path, which are inputs 240 to the system model 220, in order to optimally match demand and supply across an entire catchment while preventing water losses. The

inputs 240 to the supply of, and demand for water. The inputs 240 may include:

1. Climate forecast
2. Formal water orders
3. Soil moisture data
4. Evapotranspiration (ET) data
5. Crop details
6. Soil information
7. Water level, flow and gate opening measurements at a farm level to catchment level

[0064] Based on these inputs 240 the integrated catchment management 200 provides outputs 260 to coordinate and operate field equipment autonomously to operate the entire water distribution system from catchment to each crop/farm to optimally match the demand (downstream) and supply (upstream) both spatially and temporally. The field equipment includes a gate and/or pump in the water distribution system for example. The autonomous action may include one or more of:

- controlling a supply of water to the flow path to the flow path (e.g. by releasing water from a dam 120 or other upstream water store 130, 140, 160);
- controlling the delivery of water to the soil to utilize a capacity of the soil to accept water in response to a surplus of water and/or in anticipation of surplus water to the water distribution system (e.g. by opening exits or gates from the flow-path); and
- reducing a volume of water in a pool 140 by control gates to free up storage capacity in order to capture surplus water (e.g. by controlling the exits or gates from the flow path).

[0065] The exits or gates may be valves at the downstream ends of the canals 160.

[0066] Further the integrated catchment management 200 provides an output in the form of decision support to an operator (or farmer) to assist in operating the entire water distribution system from catchment to each farm optimally to match the demand (downstream) and supply (upstream) both spatially and temporally.

[0067] The integrated nature of the catchment management 200 (which considers multiple inputs along the water distribution system and provides one or more outputs for controlling the water distribution system) matches supply with the demand and, as a result, increases the overall efficiencies of the water distribution system.

[0068] Reliance on irrigation orders to predict demand works well in a tightly controlled water distribution system that can respond instantly and locally to this demand. Having 'forward look' forecast information on demand through such tools as soil moisture, demand patterns (irrigation practices) or weather forecasts allows operational actions to be taken that will pre-empt likely conditions that are to occur. In an operational sense, actions can be taken that take advantage of the 'elasticity' or 'give & take' in the system rather than only relying on actual events. This elasticity is usually associated with the inherent storage in the systems, whether with the channels themselves or storage facilities such as dams or weirs on the conveyance network. By using forecast data, pre-emptive operational actions can be taken to surcharge or drawdown the storage in the system to better respond to forecast events. The probability of forecasts and risk associated with actions are key parameters in these models proposed for catchment management.

[0069] The system continuously monitors the data and ensures that transportation delays and capacities in the conveyance systems, and storages on farm and in the root zone of crops are utilized to buffer and mismatches in prediction and reality, and continuously optimizes its prediction through learning algorithms.

[0070] The flow path of the water distribution system to which the integrated catchment management 200 is applied can have a length up to about 100 km. It is limited by the resolution of the weather and soil moisture measurements, satellite images and evapotranspiration data. As the resolution increases, or with more instrumentation to measure the evapotranspiration, rain and drought events and soil moisture, so does the capability of the tool to operate on smaller catchments and

farms. The weather forecasts can be integrated into the system to provide additional derived advance notice of the demand over and above that computed from the water orders as depicted in Fig. 1.

Determining the water level, flow and gate opening measurements

[0071] The inputs relating to the water level, flow and gate opening measurements may be provided by one or more supply indicators. The supply indicator is a flow meter or a level sensor for example. The supply indicators may provide information relating to:

- at least one volume of water in the water distribution system; or
- inflow of water to the water distribution system; or
- future inflow of water to the system.

[0072] In the example previously described above, in the event of a rainfall (or forecasted rainfall event), the supply indicator(s) will provide an indication of one or more of the volume of water in the upstream portion, the inflow of water to the upstream portion, and the forecasted inflow of water in the upstream portion.

[0073] Based on the indication of the current water levels at and current/forecasted inflow into the upstream portion, the water distribution system is operated to release water in the upstream portion to one or more downstream portions, if necessary, in order to allow the upstream portion to accommodate the additional inflow of water.

Determining the soil moisture

[0074] To the inventors' knowledge, there are no approaches currently to accurately extrapolate localised accurate local measurements of moisture on a spatial scale.

[0075] There are moisture sensors that can measure the moisture level in the soil near the root zone of the plant which can indicate when water should be applied to the plant. These sensors however only provide a point, or localized, measurement of the moisture in the soil for a larger crop plantation. There can be wide spatial variability associated with soil moisture because there are several factors that make the measurement of moisture in the soil specific to that site, such as;

1. Soil type, specifically its water holding capacity
2. Crop type
3. Crop condition and that stage the plants growth cycle
4. Micro-climate

[0076] The cost of these sensors and communicating their associated data precludes a large distribution of these instruments being deployed across a crop plantation.

[0077] There are sensors (instruments) that can measure these parameters on the required necessary spatial density to give a more cost-effective derivation of moisture in the soil for a wider scale crop plantation. This method can also be costly for the overall level of accuracy it provides.

[0078] Existing approaches to determine the soil moisture deficit through satellite imagery and Normalized Difference Vegetation Index (NDVI) cannot provide guarantees on accuracy of the moisture deficit as the equations to derive the deficit through evapotranspiration (ET) approaches rely on empirical equations that are calibrated around a certain data set, and there are lot of approximations involved in the computation of ET.

[0079] Computation of the crop Evapotranspiration E_{TC} is discussed below to highlight its deficiencies.

$$\text{Crop co-efficient } (Kc) = f(NDVI) \rightarrow (1)$$

$$E_{TC} = E_{TO} \cdot Kc \rightarrow (2)$$

where

E_{TC} = EvapoTranspiration at the desired surface

E_{TO} = Reference crop EvapoTranspiration

[0080] The reference crop evapotranspiration E_{TO} can be calculated using the following equation known as the Penman-Monteith equation:

$$\tau E_{To} = \frac{[\Delta(Rn - G)] + (\gamma\tau Ea)}{(\Delta + \tau)}$$

where

Δ = Slope of the saturated vapour pressure curve $[\frac{\delta e}{\delta T}]$

e = saturated vapour pressure (kPa)

T = daily mean temperature (°C)

Rn = net radiation flux ($Mjm^{-2}d^{-1}$)

G = sensible heat flux in to the soil ($Mjm^{-2}d^{-1}$)

γ = psychometric constant ($kPa\ ^\circ C^{-1}$)

τ = Latent heat of vapourization (Mj/Kg)

Ea = vapour transport of flux ($mm\ d^{-1}$)

[0081] The equation is deficient for the following reasons:

- the daily mean temperature T is the average of the maximum and minimum temperatures $((T_{max} + T_{min})/2)$. However, this information does not capture the accurate spread of temperature variations in a day.
- wind speed measurements at 2 m above ground level is required. Readings at heights other than 2 m are usually adjusted using empirical equations.
- the slope of the saturated vapour pressure curve also uses the daily mean temperature T .
- the psychometric constant γ requires atmospheric pressure as an input. The atmospheric pressure at an elevation is measured using an empirical formula assuming a temperature of $20^\circ C$ which is not always true. For at least these reasons, the set accuracy of an E_t estimated (and hence soil moisture deficit)

through a satellite and weather measurements cannot be guaranteed. Irrigation administrative regions usually span over a large area (for e.g. 27,000 sq.km). Therefore, cumulative inaccuracy on both a spatial a temporal scale on the estimation of soil moisture can result in huge supply and demand mismatches that cannot be buffered within the system, thereby either creating wastages due to excess supply, or starving the farms through inadequate supply.

[0082] The importance of determination of soil moisture and the ongoing effects it has on crops is shown in FIGURE 3. FIGURE 3 shows a graph of soil moisture against time in a sample timeline. At moisture level 10, the soil is drier enough to require irrigation to provide a healthy crop. Irrigation proceeds at line 12 and is stopped when the soil moisture reaches moisture level 14, where irrigation is no longer required. Assuming there is no rain, the soil will dry out as shown by gradient 16. The soil moisture will fall to moisture level 10 and irrigation will be required again. Irrigation again proceeds at line 18 and is stopped when the soil moisture again reaches moisture level 14, where irrigation is no longer required. The soil will dry out as shown by gradient 20. If rainfall occurs as shown by line 22, the soil moisture will increase. On cessation of rainfall, the soil will again dry out as shown by gradient 24. Accordingly, there is a longer time between irrigation cycle 28, 30 than the irrigation cycle 26, 28. If this variation is not taken into consideration when requesting irrigation of crops, the soil will be overwatered resulting in unnecessary irrigation of crops and wastage of water.

[0083] To address the deficiencies identified above and previously, the method of determining the moisture levels in the soil on a spatial scale in an irrigation area must be improved. The method of the present invention is an improvement over the Applicant's DEMAND MANAGEMENT SYSTEM FOR FLUID NETWORKS of PCT Application No. PCT/AU2012/000907 (published as WO 2013/016769 A1, the contents of which publication are incorporated herein by reference), and the Applicant's METHOD OF DEMAND MANAGEMENT AND CONTROL OF FLUID PIPE NETWORKS of PCT Application No. PCT/AU2014/050208 (published as WO 2015/031954 A1, the contents of which publication are incorporated herein by reference).

[0084] The moisture level is determined based on data indicative of one or more of the parameters set out below.

- Air temperature (e.g. air temperature at at least two points at least proximal the agricultural area). The temperature data can be obtained using temperature sensors on equipment deployed as part of the irrigation control system.
- Rainfall (e.g. rainfall at at least two points at least proximal the agricultural area). The rainfall data can be obtained using rainfall sensors incorporating the necessary density of rainfall sensors on equipment deployed as part of the irrigation control system. Rainfall has strong spatial variability (i.e. in a given area, the rainfall is not uniform spatially).
- Wind speed (e.g. wind speed at at least two points at least proximal the agricultural area). The wind speed data can be obtained using wind speed sensors on the equipment deployed as part of the irrigation control system. Wind speed has medium spatial variability.
- Relative humidity (e.g. relative humidity at at least two points at least proximal the agricultural area). The relative humidity data can be obtained by incorporating the necessary density of rainfall sensors on the equipment deployed as part of the irrigation control system. Relative humidity has low spatial variability
- Barometric pressure at at least two points at least proximal the agricultural area).
- Proximal solar intensity. The solar intensity can be determined from an output of a solar panel (i.e. as an energy measurement) deployed as part of the irrigation control system.
- An inherent characteristic of the soil including soil types and water holding capacity (e.g. inherent characteristic of the soil at at least two points at least proximal the agricultural area). Soil type can be determined by ground penetrating radar to develop a relationship between the radar signal and the water holding capacity of the soil;

- An irrigation history associated with the agricultural area (e.g. history relating to each irrigation supplied to a farm – how much water was supplied, when was the water supplied, was the soil moisture a maximum or saturated following the supply of water).
- Satellite data (e.g. an energy density for visible light or an energy density for near- infrared light). The satellite data can provide spatially variable measurements of the intensity (W/m^2) of solar radiation spectrums for visible light (having wavelengths of $0.4\mu m$ to $0.7\mu m$) and near-infrared light (having wavelengths of $0.7\mu m$ to $1.1\mu m$).

[0085] FIGURE 4 shows an enlarged view of a modified gate or regulator 132 described with reference to FIGURE 1. A remote computer system 150 is depicted by a laptop that communicates with all gates or regulators 132 and moisture sensors 500 (FIGURE 5). A weather station 152 is fitted to pedestal 136 and is powered through solar panel 134 at each location. Suitable weather stations 152 are available which can provide measurements of temperature, rainfall, wind speed, relative humidity, weather forecast and UV. Weather stations 152 can be readily incorporated in the design of gates or regulators 132 or can be retrofitted to already existing gates or regulators 132. The network of weather stations enhances the measurement and prediction of weather forecasts for meteorologists and farmers. The network provides the concept of a network of weather stations used individually by farmers but part of a wider shared network through the concept of a cluster of networked weather stations. This is achieved through the ability to interpolate the information on the network of weather stations.

[0086] Some of the sensors described above may be in the agricultural area.

[0087] The data may, for example, be received from a photovoltaic powering a water control barrier or gate, a pump, a flow meter and a water level sensor or any electromechanical device.

[0088] FIGURE 5 is a similar view to that of FIGURE 1 and the same reference numerals have been used to avoid duplication of description. Each gate or regulator 132 or group of gates or regulators 132 includes a weather station 152 (FIGURE 4) linked to a remote computer system depicted at 502. A soil moisture sensor 500 is

positioned amongst the crops 190. The soil moisture sensor 500 is wired or wirelessly linked to the computer network with the gates and regulators 132 and the weather stations 152. The soil moisture sensors 500 are spread throughout the irrigation district and are substantially less in number than the gates or regulators 132. Suitable soil moisture sensors are sold under the trade marks AQUASPY or SENTEK.

[0089] In determining the moisture data, the method includes determining and applying a model having parameters adjusted to suit the agricultural area.

[0090] In applying the logic, the method (additionally/alternatively) includes applying a model derived from system identification. System Identification techniques are used to produce an algorithm that derives evapotranspiration on a spatially variable scale that can be used to determine the moisture in the soil on the same spatially variable scale. Calibration of the algorithm will be achieved by the direct measurement of the moisture in the soil using sensors 500 distributed throughout the irrigation area and providing good representation of spatial variability of the input data.

[0091] The spatial density of the measurement will be dependent of the spatial variability of the specific input parameters. Point source measurements, e.g. soil moisture, can be used to ground truth or calibrate measurements from satellites that provide high spatial variability but do not have high accuracy levels.

[0092] There are two methods of determining/deriving the soil moisture on a continuous/contour basis for an area of land:

1. Derive soil moisture from a selection of the raw inputs (rainfall, temperature, humidity, solar radiation, wind speed, crop factor, soil type, barometric pressure, irrigation historical data and energy from solar panels) for each individual weather station 152 and then interpolate soil moisture based on the fact that weather stations 152 are on a grid network (density, spacing etc.) that provides a good spatial representation of the soil moisture.
2. First interpolate the raw inputs based on the grid network of weather stations 152 (plus satellite spatial determination of crop factor) and then compute the spatial soil moisture.

[0093] This information will also be used as an aid to irrigation farmers in determining the best time to irrigate their crop.

[0094] Software tools will prompt irrigators on a real-time basis on any changes to the suggested time to irrigate. The system will be integrated with the water ordering software of the Applicant's DEMAND MANAGEMENT SYSTEM FOR FLUID NETWORKS of PCT Application No. PCT/AU2012/000907 (published as WO 2013/016769 A1, the contents of which publication are incorporated herein by reference) to facilitate efficient irrigation practices and the ease of use of the system.

[0095] Soil moisture at $(x, y, t) =$

$$\text{Soil moisture reference stations} \left(\begin{matrix} x_1 & y_1 \\ \vdots & \vdots \\ x_n & y_n \end{matrix}, t \right) \cdot f(\text{Solar radiation, satellite data, soil type, rainfall, wind speed, irrigation historical data, temperature \& humidity, } t)$$

where

x and y = geographical co – ordinates

t = time

[0096] The parameters of the function f will be calibrated and validated using real time accurate data collected using field instrumentation located in the irrigation area.

[0097] Soil moisture at other areas in the farm can be determined by extrapolating the soil moisture measurements made any other point at the farm. In extrapolating the data, the method also considers one or more of soil types, crop types, crop growth stages, and satellite measurements between the point at which the measurement is made and the point at which soil moisture is to be determined.

Determining evapotranspiration

[0098] Referring to FIGURE 4, the present invention provides a system 300 and method for estimating evapotranspiration (ET) data using indirect measurements available in remote areas. In particular, the present invention makes use of an output of the array of solar panels 134 used to power existing devices used

throughout the water distribution system, such as gate or regulator 340. The solar powered devices may also include a range of devices including sensors (such as the sensors 500 previously discussed for determining soil moisture), a water control barrier, a pump, a flow meter, a water level sensor, and any electromechanical device used in the water delivery system.

[0099] Existing methods of determining ET are based on satellite measurements. Because the measurements in this invention are made closer to the farm, the method of the present invention is more accurate than the existing methods of determining ET.

[00100] Solar powered devices are becoming more prevalent in the agriculture and irrigation sector. These solar powered devices provide immense an opportunity to utilize the solar data for other useful purposes including estimating the ET.

[00101] Solar cells convert energy from the photons in sunlight to the electrons in the solar cell. The more photons of sunlight absorbed by the solar cell, the greater the current output.

Current output of the photovoltaic cell \propto Solar intensity

However,

EvapoTranspiration \propto Solar intensity

Therefore,

EvapoTranspiration \propto Current output of the Photovoltaic cell

[00102] A number of other factors can be considered to improve the ET calculation including the age of the photovoltaic cell, the temperature, the crop type and growth stage, the soil type, irrigation events, wind information. Hence, the ET can be determined from the following equation:

	<i>Current output of the photovoltaic cell</i>
	<i>Age of the photovoltaic cell,</i>
-	<i>Temperature,</i>
<i>EvapoTranspiratio(t) = f</i>	<i>Crop type & growth stage,</i>
-	<i>Soil type,</i>
-	<i>Irrigation events,</i>
	<i>Wind information</i>
	t

where

t = time

[00103] The parameters of the function f will be calibrated through real time data from photovoltaic cells in the field as well as other inputs on temperature, crop type and its growth stage and soil type.

Example 1

[00104] An example operation of the network catchment management of the present invention will now be described with reference to FIGURE 6. The integrated catchment management system of the present invention provides an optimal convergence of supply and demand, and judicial utilization of the elasticity/buffer within the system.

[00105] At step 510, the integrated catchment management system uses satellite evapotranspiration data and/or farm soil moisture data predicted by extrapolating the soil moisture measurements made at any other point at the farm to:

- predict the optimal date of a farm's next irrigation;
- optionally inform the customer of the optimal date (by text message or email); and

- predict future inflows in a water basin and storage based on weather data and live measurements of flows and water levels.

[00106] The system then establishes the demand and to establish the supply in both space and time; and ensures that the water demand is within the supply constraints. In this example, the 'demand' is the water requirement at the farm level, and the 'supply' is the water availability in the basin. At step 520, the system receives a request from a customer for irrigation water, which is then managed on a water authority's server.

[00107] At step 530, if capacity in the canal network is available at the requested time and the customer has sufficient water in their water bank account, the order is automatically accepted. If the capacity is insufficient, the system will offer an alternative time to the customer. The system will also continuously measure the storages in the water distribution system (pools), offline storage, and crops root zone in anticipation of a flood or a shortfall.

[00108] At step 540, the system identifies the cross-regulators and the farm service point needed to deliver the order. In addition, the system identifies the pools or farms with the spare storage. Radio node towers receive this information and send instructions to the appropriate automated gate cross-regulators and to the customer's service point.

[00109] The Applicant's DEMAND MANAGEMENT SYSTEM FOR FLUID NETWORKS of PCT Application No. PCT/AU2012/000907 (published as WO 2013/016769 A1, the contents of which publication are incorporated herein by reference), and the Applicant's METHOD OF DEMAND MANAGEMENT AND CONTROL OF FLUID PIPE NETWORKS of PCT Application No. PCT/AU2014/050208 (published as WO 2015/031954 A1, the contents of which publication are incorporated herein by reference) describe methods and system for ensuring that the demand does not exceed the supply, and that any violations (i.e. demands that exceed the supply constraints) are appropriately rescheduled as per business rules that suites operations of each irrigation region, which can be used with embodiments of the present invention.

[00110] The system then ensures that water is transported from its source to its destination points at high efficiency (i.e. with minimal water losses and/or at a steady flow rate). At step 550, the system automatically pre-empts the cross-regulator in the canal and adjust the pool setpoints to buffer any mismatches in supply from the water source. The system will lower the pool setpoints to create extra storage in anticipation of excess inflow (or floods). Alternatively, the system will surcharge the pools within constraints in the event of a short fall prediction. The customer's farm service point will normally automatically open at the scheduled time, deliver the requested flow rate for the duration of the order and then automatically close. In the event of a known prediction of a known excess inflow or shortfall, the operator/farmer will be allowed to move his order to start early or to delay his order to create a buffer in the water distribution system and storages.

[00111] At step 560, the automated gates along the water distribution system immediately adjust their flow rate to:

- take the pools to its new set point;
- replenish the water being withdrawn by the customer's and all other concurrent orders;
- maintain constant water levels at its new setpoint irrespective of flow changes.

[00112] At step 570, when irrigation is complete, the software uses service point meter and order information to calculate the amount of water supplied to the customer and deducts it from the customer's water bank account. The customer is automatically invoiced and optionally issued a statement. When the flood or shortfall event is completed, the system provides automatic commands to the cross-regulators to take their respective pools to the normal setpoints.

[00113] The Applicant's FLUID REGULATION of PCT Application No. PCT/AU2002/000230 (published as WO 2002/071163 A1, the contents of which publication are incorporated herein by reference) Patent No 2011903084, and the Applicant's SUPERVISORY CONTROL OF AUTOMATED IRRIGATION CHANNELS of PCT Application No. PCT/AU2013/000355 (published as WO

2013/149304 A1, the contents of which publication are incorporated herein by reference) describe methods and systems for providing decision support for water delivery or the actual physical water delivery from the basin to the crops.

[00114] As a holistic view of the network and its real-time status is available, the transportation delays, spare capacities in the conveyance systems, and storages on farm and in the root zone of crops can be exploited to buffer mismatches in prediction and reality. Thereby the system is able to mitigate the impact of extreme events such as floods and flow shortfalls.

[00115] Knowing in advance when all farmers will irrigate is also an important input for the integrated catchment management system and the ability to pre-empt demand in order to enact an optimal control strategy for the water network within the catchment.

[00116] The localised accurate readings are extrapolated spatially through characterised equations that is a function of the soil types (specifically its water holding capacity), crop type, crop condition and stage of plants growth cycle, weather information (wind, temperature, saturated vapour pressure), and satellite measurements.

[00117] The timing of when to apply water to a crop is a key decision process within irrigation farming practices. Determining when the crop needs to be replenished can impact on the resultant yield from the planted crop as well as the total amount of water used.

[00118] The invention differs from the prior art as it discloses methods and systems where the interpolation or derivation of data is based on a substantial reduction of expensive soil moisture sensors. The determination of soil moisture at any location within the irrigation district can be made without requiring a soil moisture sensor at that location. The soil moisture sensors are used to provide ongoing refinement and calibration of the system deriving soil moisture using climatic data.

[00119] Embodiments of the invention have been described above by way of non-limiting example only. Variations and modifications to the embodiments may be made without departing from the scope of the invention.

The claims defining the invention are as follows:

1. A method of spatially deriving the soil moisture at a selected location within an irrigation district to be irrigated, said method including the steps of:

using system identification techniques to produce an algorithm for evapotranspiration based on a predetermined selection from the following measured parameters: solar radiation spectrum, wind speed, temperature, humidity, crop factor, soil type, barometric pressure, irrigation historical data, and energy measurement from solar panels at each of a plurality of representative locations;
calibrating said algorithm by direct measurement of the moisture in the soil at each of said representative locations by respective soil moisture sensors; and
using measured parameters of rainfall, soil type, irrigation historical data and crop factor with said algorithm to derive or interpolate soil moisture at said selected location within said irrigation district.

2. The method of claim 1, wherein said soil type is determined by ground penetrating radar to develop a relationship between the radar signal and the water holding capacity of the soil.

3. The method of any one of the preceding claims, wherein said irrigation historical data is based on the time and volume of the irrigation to provide saturation data on said soil moisture.

4. The method of any one of the preceding claims, wherein said solar radiation spectrum includes visible light and near-infrared light.

5. The method of any one of the preceding claims, further including an irrigation management system to irrigate predetermined areas of said irrigation district based on the determination of said soil moisture for said predetermined areas, availability of irrigation water and requests for timed irrigation from end users.

6. The method of claim 5, wherein said irrigation management system monitors an irrigation conveyance network from catchments to supply water to areas to be irrigated under demand by said end users.
7. The method of claim 5 or 6, wherein said irrigation management system monitors said soil moisture at said plurality of representative locations and monitors at least one or more of climate forecast, water orders from end users, crop details, water levels, and flow gate opening measurements of said irrigation district.
8. A soil moisture determination system to spatially derive the soil moisture at a selected location within an irrigation district to be irrigated, said system including a networked computer system connected to a plurality of weather stations within said irrigation district to measure a selection from: solar radiation spectrum, wind speed, rainfall, temperature, humidity, barometric pressure, and energy measurement from solar panels at each of a plurality of representative locations, said networked computer system having data access to crop factor, soil type, and irrigation historical data at said representative locations, said networked computer system using system identification techniques to produce an algorithm for evapotranspiration based on a predetermined selection from the weather station measurements and the data access to crop factor, soil type, and irrigation historical data at said representative locations ; said networked computer system calibrating said algorithm by direct measurement of the moisture in the soil at each of said representative locations by respective soil moisture sensors; and using measured parameters of rainfall, soil type, irrigation historical data and crop factor with said algorithm to derive or interpolate soil moisture at said selected location within said irrigation district.
9. The soil moisture determination system of claim 8, wherein said soil type is determined by ground penetrating radar to develop a relationship between the radar signal and the water holding capacity of the soil.
10. The soil moisture determination system of claim 8 or 9, wherein said irrigation historical data is based on the time and volume of the irrigation to provide saturation data on said soil moisture.

11. The soil moisture determination system of any one of claims 8 to 10, wherein said solar radiation spectrum includes visible light and near-infrared light.
12. An irrigation management system to irrigate predetermined areas of an irrigation district including the soil moisture determination system of any one of claims 8 to 11, said irrigation management system based on the determination of said soil moisture for said predetermined areas, availability of irrigation water and requests for timed irrigation from end users.
13. The irrigation management system of claim 12, wherein said irrigation management system monitors an irrigation conveyance network from catchments to supply water to areas to be irrigated under demand by said end users.
14. The irrigation management system of claim 12 or 13, wherein said irrigation management system monitors said soil moisture at said plurality of representative locations and monitors at least one or more of climate forecast, water orders from end users, crop details, water levels, and flow gate opening measurements of said irrigation district.
15. The irrigation management system of claim 14 wherein said weather stations are included with a plurality of said flow gates.
16. A method of controlling a water distribution system; the system having at least one at-least-predominantly-free-surface flow-path from which water is deliverable to soil; and
the method including controlling the system based on at least a moisture level of the soil; and at least one supply indicator; the at least one supply indicator being an indicator of at least one of at least one volume of water in the system; an inflow of water to the system; and a future inflow of water to the system.
17. The method of claim 16 wherein the controlling includes causing water to be delivered to the soil to utilize a capacity of the soil to accept water at least one of in response to a surplus of water; and

in anticipation of a surplus of water.

18. The method of claim 17 wherein the system includes a system portion from which the water is so delivered; and the method includes reducing a volume of water in the system portion to make storage capacity within the system portion available to capture surplus water.

19. A method of controlling a water distribution system; the system having at least one at-least-predominantly-free-surface flow-path; and the method including delivery water from the flow-path in accordance with a delivery schedule; receiving at least one supply indicator being an indicator of at least one of

at least one volume of water in the system; an inflow of water to the system; and a future inflow of water to the system; and

at least influencing the delivery schedule based on the at least one supply indicator.

20. The method of any one of claims 16 to 19 wherein the flow path is at least 100 km long.

21. The method of any one of claims 16 to 20 wherein the at least one supply indicator is an indicator of at least one of

at least one volume of water in the system upstream of the flow path;

an inflow of water to the system upstream of the flow path; and

a future inflow of water to the system upstream of the flow path.

22. The method of any one of claims 16 to 21 wherein the controlling includes controlling a supply of water to the flow path.

23. A method including utilizing as an indication of solar intensity an output of at least one photovoltaic powering a device.
24. A method, of estimating at least one of a moisture level of soil and an evapotranspiration from the soil, including applying logic to an output of at least one photovoltaic powering a device.
25. A method, of estimating a spatially-variable estimate of soil moisture level across an agricultural area, including applying logic to data indicative of at least air temperature; rainfall; wind speed; relative humidity; solar intensity; and one inherent characteristic of the soil.
26. The method of claim 25 wherein the data is indicative of an irrigation history associated with the agricultural area.
27. The method of claim 25 or 26 wherein the data is indicative of air temperature at at least two points at least proximal the agricultural area.
28. The method of any one of claims 25 to 27 wherein the data is indicative of rainfall at at least two points at least proximal the agricultural area.
29. The method of any one of claims 25 to 28 wherein the data is indicative of wind speed at at least two points at least proximal the agricultural area.
30. The method of any one of claims 25 to 29 wherein the data is indicative of relative humidity at at least two points at least proximal the agricultural area.
31. The method of any one of claims 25 to 30 wherein the data is indicative of an energy density for visible light.
32. The method of any one of claims 25 to 31 wherein the data is indicative of an

energy density for near-infrared light.

33. The method of any one of claims 25 to 32 wherein the data is indicative of the at least one inherent characteristic of the soil at at least two points at least proximal the agricultural area.

34. The method of any one of claims 25 to 33 wherein the data includes an output from at least one soil-moisture sensor at least proximal the agricultural area.

35. A method, of estimating a spatially-variable estimate of soil moisture level across an agricultural area, including applying logic to data indicative of at least an output from at least one soil-moisture sensor at least proximal the agricultural area; and spatially-variable satellite data.

36. The method of claim 35 wherein the data is indicative of an energy density for visible light.

37. The method of claim 35 or 36 wherein the data is indicative of an energy density for near-infrared light.

38. The method of any one of claims 25 to 37 including applying logic to an output of at least one photovoltaic powering a device.

39. The method of claim 23, 24 or 38 wherein the device is an electromechanical device.

40. The method of claim 23, 24, 38 or 39 wherein the device is one or more of a water control barrier, a pump, a flow meter and a water level sensor.

41. The method of any one of claims 10 to 23 wherein the applying logic is applying a model having parameters adjusted to suit the agricultural area.

42. The method of any one of claims 25 to 38 wherein the applying logic is applying a model derived from system identification.

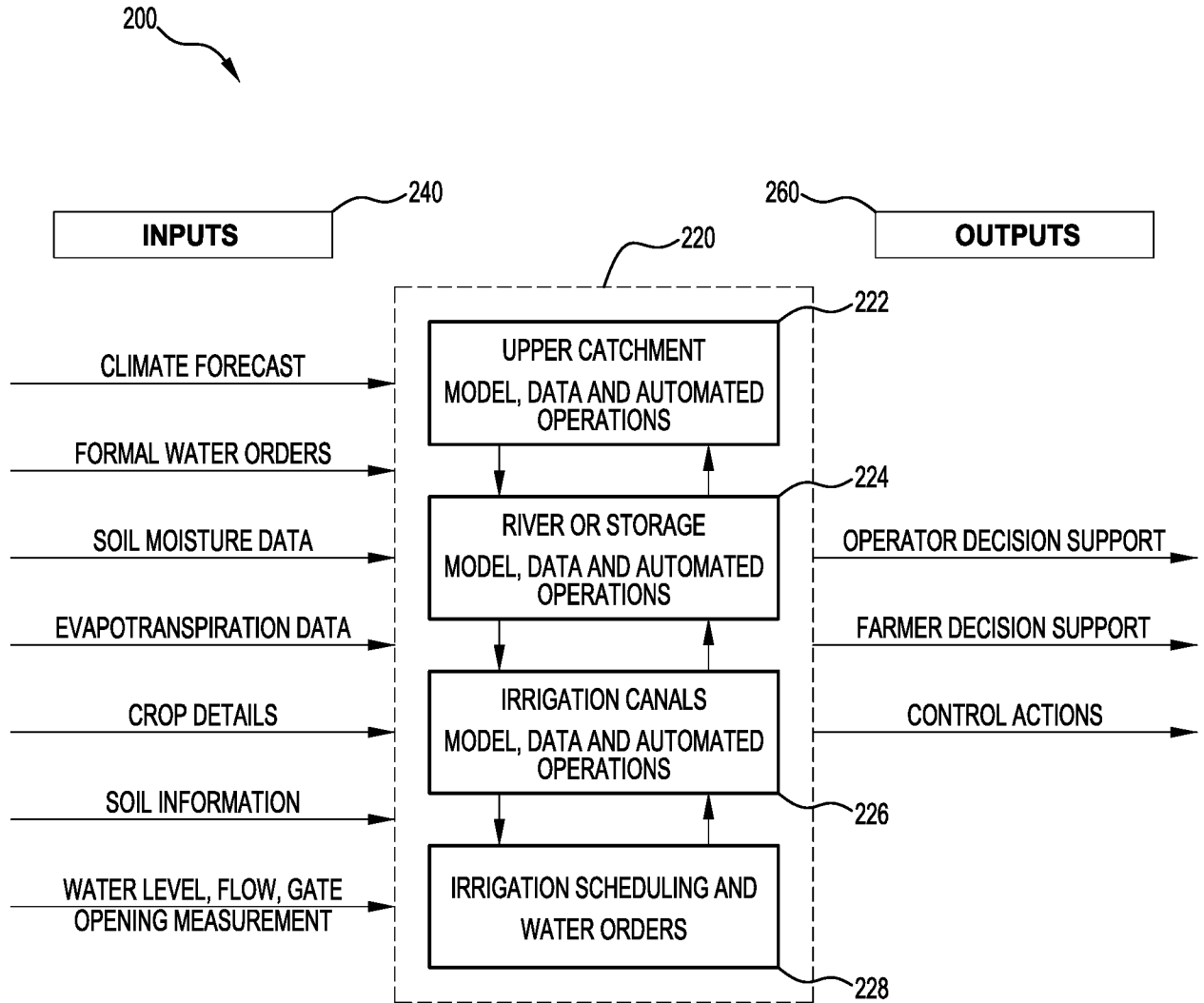


Figure 2

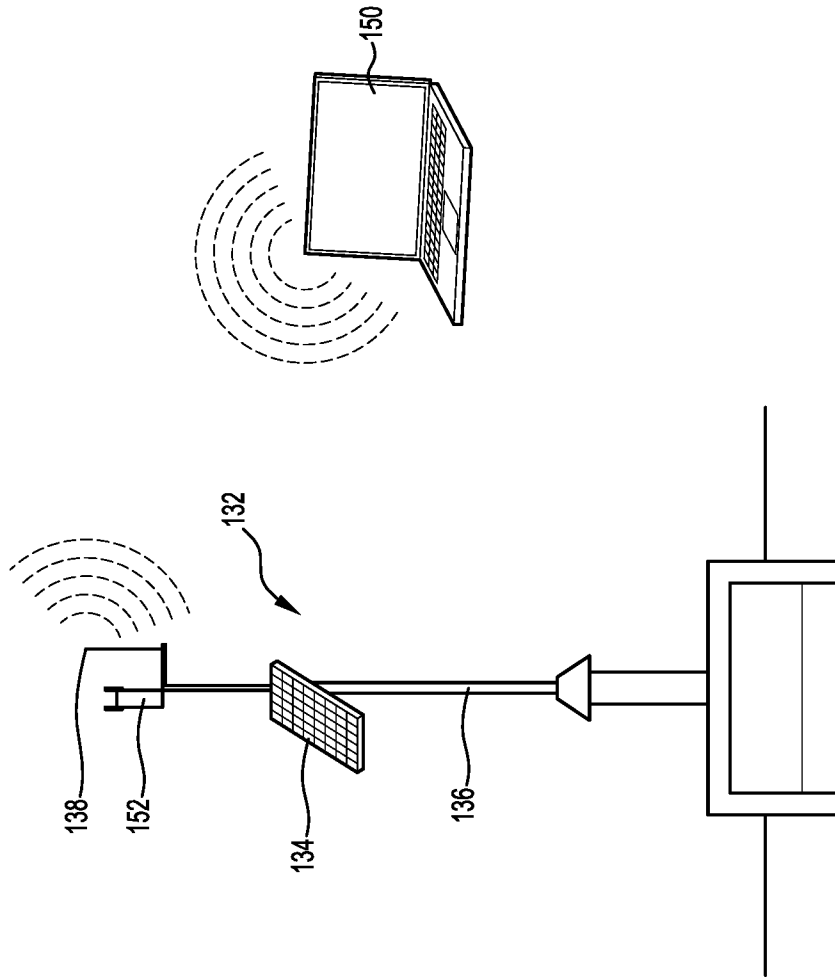


Figure 4

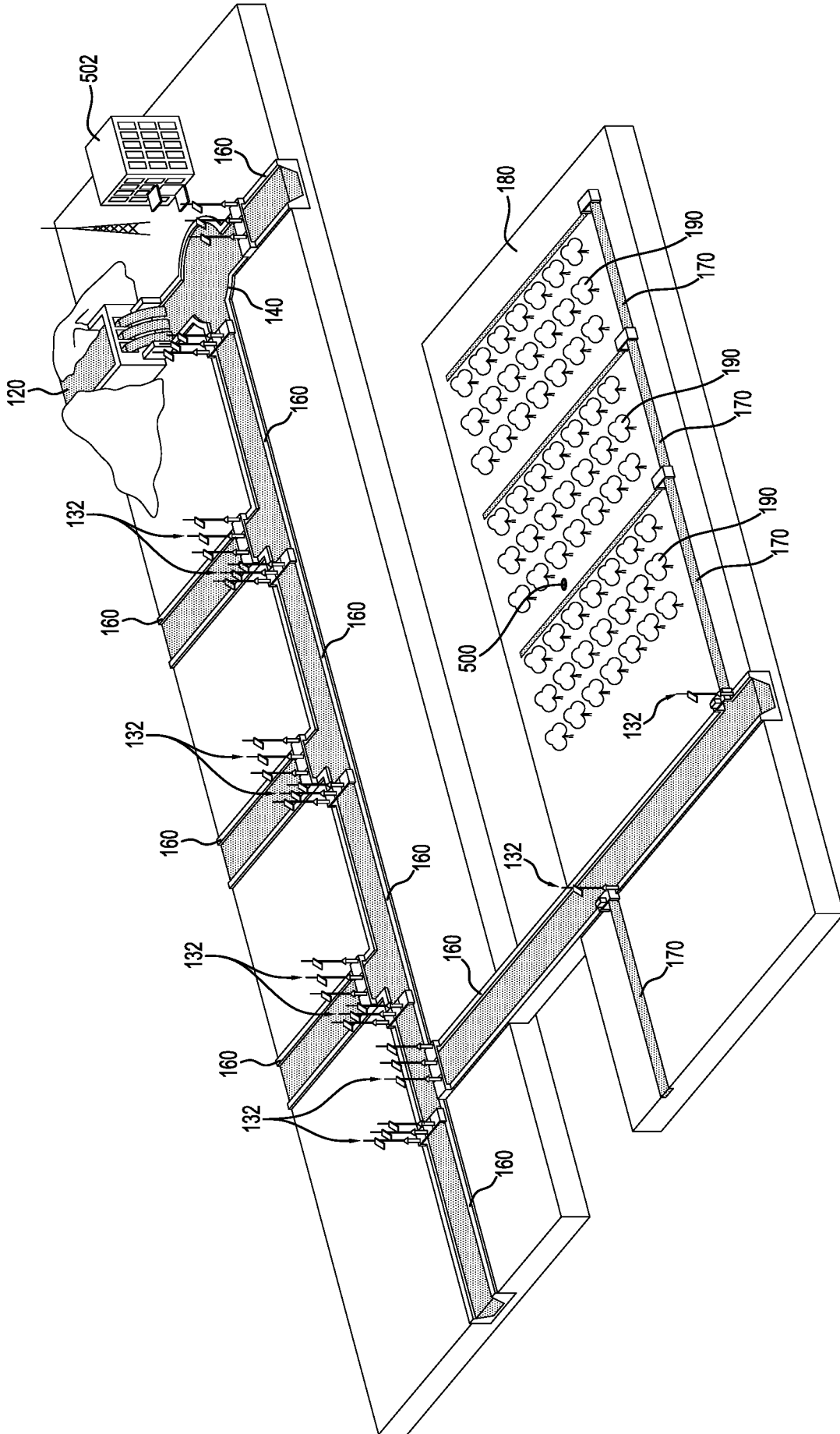


Figure 5

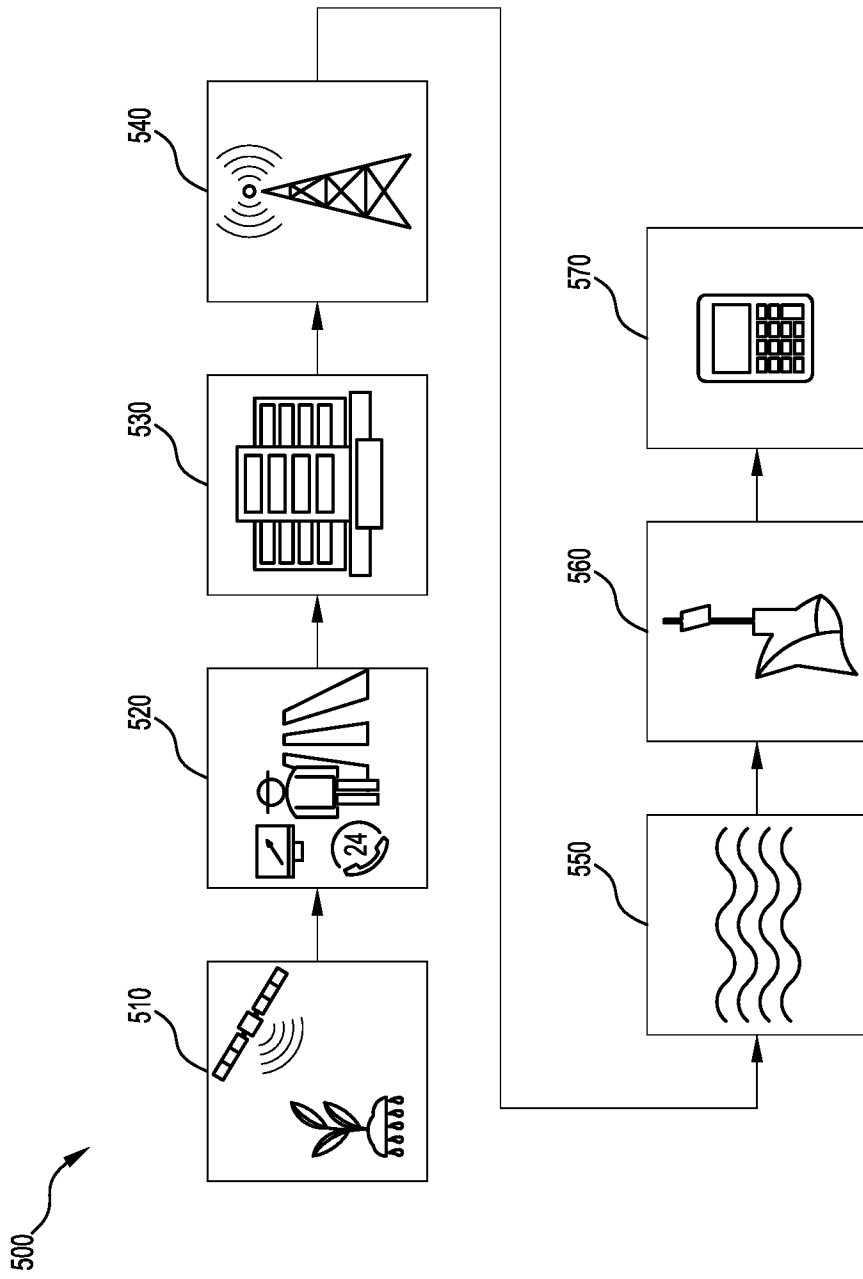


Figure 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/AU2018/050858

A. CLASSIFICATION OF SUBJECT MATTER

A01G 25/00 (2006.01) A01G 25/16 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Applicant(s)/inventor(s) name searched in internal databases provided by IP Australia, Espacenet, AusPat and Google. Search query: "RUBICON RESEARCH PTY LTD", "THE UNIVERSITY OF MELBOURNE" as the applicant(s) AND/OR "Aughton, David John", "Choy, Sumith", "Mareels, Iven Michiel Yvonne", "Ryu, Dongryeol", "Western, Andrew" as the inventor(s). EPOQUE INTERNAL: PATENW: EPODOC, WPIAP, TXPEA, TXPEB, TXPEC, TXPEE, TXPEF, TXPEH, TXPEI, TXPEP, TXPES, TXPEPEA, TXPUSE0A, TXPUSE1A, TXPUSEA, TXPUSEB, TXPW0EA. IPC, CPC; A01G25/167/LOW, E02B13/-, A01G25/16/LOW, G05D7/0617/LOW, A01G25/-, G05D7/- and Keywords: ground, radar, probe, sensor, moisture, network, computer, algorithm, solar, catchment, irrigation, conveyance, water, rainfall and like terms. Google Patent Search: Keywords: soil, measure moisture, spatial, determination, irrigation, networked, computer system, connected, plurality, weather stations, solar radiation spectrum, wind speed, temperature, humidity, barometric pressure, and energy measurement, solar panels, data access, crop factor, soil type, irrigation historical data, representative locations, system identification techniques, produce algorithm, evapotranspiration, calibrating algorithm, moisture sensors, measured rainfall, interpolate soil moisture, within irrigation district, ground penetrating radar, signal, water holding capacity of the soil, irrigation management system, conveyance network, catchments, end user demand, plurality flow gates, at-least-predominantly-free-surface flow-path, deliver water, supply indicator, storage capacity, capture surplus water, control water distribution, delivery schedule, applying logic, photovoltaic powering a device, visible light, infrared light, spatially-variable satellite data and like terms. Google Patent Search: Keywords: soil, measure moisture, spatial, determination, irrigation, networked, computer system, connected, plurality, weather stations, solar radiation spectrum, wind speed, temperature, humidity, barometric pressure, and energy measurement, solar panels, data access, crop factor, soil type, irrigation historical data, representative locations, system identification techniques, produce algorithm, evapotranspiration, calibrating algorithm, moisture sensors, measured rainfall, interpolate soil moisture, within irrigation district, ground penetrating radar, signal, water holding capacity of the soil, irrigation management system, conveyance network, catchments, end user demand, plurality flow gates, at-least-predominantly-free-surface flow-path, deliver water, supply indicator, storage capacity, capture surplus water, control water distribution, delivery schedule, applying logic, photovoltaic powering a device, visible light, infrared light, spatially-variable satellite data and like terms.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Documents are listed in the continuation of Box C	

Further documents are listed in the continuation of Box C

See patent family annex

* "A"	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E"	earlier application or patent but published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search
28 August 2018Date of mailing of the international search report
28 August 2018

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INTERNATIONAL SEARCH REPORT		International application No.
C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		PCT/AU2018/050858
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2016/0048135 A1 (HILL) 18 February 2016 Abstract, figures 11-17 and paragraphs [0270]-[0338]	1-5, 7-12, 14, 15, 23-42
X	US 2015/0272017 A1 (LANDCARE RESEARCH NEW ZEALAND LIMITED) 01 October 2015 Abstract, figures 1-9 and paragraphs [0074]-[0154]	1, 3, 5-8, 10, 12-22, 25-30, 33-35, 41, 42
X	US 2016/0088807 A1 (INTERNATIONAL BUSINESS MACHINES CORPORATION) 31 March 2016 Abstract, figures 1-5B and paragraphs [0024]-[0052]	1-5, 7-12, 14, 15, 25-37, 41, 42
X	WO 2016/070195 A1 (PURDUE RESEARCH FOUNDATION) 06 May 2016 & US 2017/0311559 A1 (PURDUE RESEARCH FOUNDATION) 02 November 2017 Abstract, figures 1-3 and paragraphs [0012]-[0066]	1-3, 5, 7-10, 12, 14, 24-30, 33-35, 39-42

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
the subject matter listed in Rule 39 on which, under Article 17(2)(a)(i), an international search is not required to be carried out, including
2. Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a)

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See Supplemental Box for Details

1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- No protest accompanied the payment of additional search fees.

Supplemental Box**Continuation of: Box III**

This International Application does not comply with the requirements of unity of invention because it does not relate to one invention or to a group of inventions so linked as to form a single general inventive concept.

This Authority has found that there are different inventions based on the following features that separate the claims into distinct groups:

- Claims 1-15 and 25-42 are directed to a method / a soil moisture determination system, to spatially derive the soil moisture within an irrigation district to be irrigated, using system identification techniques to produce an algorithm for evapotranspiration, calibrating said algorithm by direct measurement of the moisture in the soil at each of said representative locations by respective soil moisture sensors; and using measured parameters of rainfall, soil type, irrigation historical data and crop factor with said algorithm to derive or interpolate soil moisture within said irrigation district.
- Claims 16-22 are directed to a method of controlling a water distribution system; the system having at least one at-least-predominantly-free-surface flow-path from which water is deliverable to soil.
- Claims 23, 24 is directed to a method including utilizing as an indication of solar intensity an output of at least one photovoltaic powering a device.

PCT Rule 13.2, first sentence, states that unity of invention is only fulfilled when there is a technical relationship among the claimed inventions involving one or more of the same or corresponding special technical features. PCT Rule 13.2, second sentence, defines a special technical feature as a feature which makes a contribution over the prior art.

When there is no special technical feature common to all the claimed inventions there is no unity of invention.

In the above groups of claims, the identified features may have the potential to make a contribution over the prior art but are not common to all the claimed inventions and therefore cannot provide the required technical relationship. Therefore there is no special technical feature common to all the claimed inventions and the requirements for unity of invention are consequently not satisfied *a priori*.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/AU2018/050858

This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document/s Cited in Search Report		Patent Family Member/s	
Publication Number	Publication Date	Publication Number	Publication Date
US 2016/0048135 A1	18 February 2016	US 2016048135 A1	18 Feb 2016
US 2015/0272017 A1	01 October 2015	US 2015272017 A1	01 Oct 2015
		AU 2013341873 A1	28 May 2015
		CA 2890328 A1	15 May 2014
		CN 105050385 A	11 Nov 2015
		EP 2916647 A1	16 Sep 2015
		HK 1214919 A1	12 Aug 2016
		SG 11201503523S A	29 Jun 2015
		US 2016157446 A1	09 Jun 2016
		WO 2014073985 A1	15 May 2014
		US 2016/0088807 A1	31 March 2016
US 9943046 B2	17 Apr 2018		
US 2018192599 A1	12 Jul 2018		
WO 2016/070195 A1	06 May 2016	WO 2016070195 A1	06 May 2016
		EP 3211987 A1	06 Sep 2017
		US 2017311559 A1	02 Nov 2017

End of Annex

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

Form PCT/ISA/210 (Family Annex)(January 2015)