Regional Application of the Curve Number Method

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A sample of 109 watersheds scattered through the US is analyzed for goodness of fit to the CN rainfall-runoff equation (with and without the constraint of Ia=0.2S), and to the linear equation Q=a+bP. The linear equation fit best 85% of the time. For the CN equation, the best fit Ia value was not 0.2S, but 0.0 in most cases. There was little apparent regional clustering of equation preference. A categorization of rainfall-runoff relationships is suggested.

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PROBLEMS TO AVOID WITH DRIP/TRICKLE IRRIGATION SYSTEMS

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ABSTRACT: Drip irrigation systems must be tailored to specific field and water conditions before specific problems can be minimized by proper design, installation, maintenance, and management. Problems to avoid are discussed, and twenty-eight suggestions are made for improving drip systems.

INTRODUCTION

Drip/trickle irrigation is the slow, precise application of water through emitters placed on a lateral plastic line located near the plant. Potential advantages over other irrigation methods include increased beneficial use of available water, enhanced plant growth and yield, improved fertilizer applications, and improved cultural practices. Potential disadvantages include continuous maintenance requirements, salt accumulation near plants, restricted plant root development, and high initial costs (6).

Significant advances have been made in drip irrigation operation within the past decade. Most of the earlier manufacturing problems have been corrected, and numerous equipment improvements have been developed so that drip irrigation has gained wide acceptance. In this paper, we will discuss the more important suggestions for the continued improvement of drip irrigation systems in terms of three principle factors--design, maintenance, and management.

DESIGN AND INSTALLATION

The main goal when designing a drip system is to insure an acceptable uniformity of water and fertilizer application throughout the field. The designer of a drip system must consider the emitter type, drip emitters, hydraulics, topography, desired water distribution uniformity, crop salt tolerance and water requirements, water quality, fertilizer injection, soil salinity, cultural practice, and other site-specific variables.

Hydraulically induced pressure variations along a drip line (main, submain, or lateral) are caused by pipeline friction losses, fitting losses, and elevation changes. Emitter discharge rate, spacing, and number per plant will also affect the pipeline hydraulics; however, procedures and details are available for the

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proper sizing of drip lines (1, 13, 15). Design charts for different field slopes, shapes, and pipe sizes by Wu, et al. (21) are particularly useful. One basic item that is often overlooked is that lateral lines should run on the flat, downhill, or along the contour. Water and fertilizer distribution uniformity is a function not only of hydraulic variation, but also of emitter performance. Variations in emitter flow rate at a given pressure can be caused by manufacturing differences, clogging, water temperature fluctuations, and aging or wear. Uniformity can be greatly reduced even when 5 percent of the emitters are completely clogged (17); and further, the variability caused by manufacturing and clogging could be larger than hydraulic variation (3). Emitter variation can also be greatly increased with the length of operation (6). Because of these results, we recommend that lateral lines with inside diameters of 13.2 or 15.2 mm (0.52 or .60 in) not be designed longer than 150 m (500 ft) for tree and vineyard crops and 200 m (660 ft) for row crops, subject to further hydraulic limitations. Submain lines should then be limited to 200 m (660 ft) or less and in some cases 100 m (330 ft) to maintain water distribution uniformity and still provide a convenient subunit size. Two-to-four hectare (5-to-10-acre) subunits are adequate for management purposes and should not interfere with farming practices.

Drip design must also consider the peak water use of the crop so that the application rate per unit area or system capacity can meet such a demand. This is particularly essential where irrigation provides the major or only source of water to the crop. Methods for estimating peak evapotranspiration (ET) or consumptive water use from meteorological data are available from various sources (8, 9, 10, 14). We then recommend that the system have the capacity to deliver the peak water use in 90 percent of the time available, or not more than about 22 hours of operation per day, to allow for possible shutdown periods caused by power failure or equipment breakdown.

Another important design consideration is water quality, for two reasons--suitability for crop production and requirements for system maintenance. Water quality for crop production is normally based on three criteria: (1) salinity, the general effects of dissolved salts or crop growth associated with osmotic stress, (2) sodicity, the effect of an excessive proportion of sodium that causes a deterioration of soil structure, and (3) toxicity, the effects of specific solutes that damage plant tissue or cause an imbalance in plant nutrition. Surface drip systems are preferred to subsurface drip systems where salinity is a hazard. The continuous upward movement from a subsurface system results in rapid salt accumulation near the soil surface as water is lost by evapotranspiration. Subsurface systems do not provide the means for removing the accumulated salt unless the soil can be leached by rainfall or other irrigation methods. Where salinity is not a real problem, subsurface drip irrigation offers excellent potential for consecutive or multiple cropping of small fruit and vegetable crops (7).

The type of practices needed to prevent clogging depends on both water quality and drip emitter design. All drip irrigation systems require some type of water filtration system. A tentative guide for the selection of a filtration unit based on flow range and suspended

materials is presented in Table 1. As a general rule, filtration units should be designed with at least 20 percent extra capacity. Pump sizes should also be increased accordingly to provide some reserve operating pressure and capacity for backwashing filters and flushing drip lines.

Table 1. Tentative guide for selecting an appropriate type of filtration system with drip irrigation systems.

Type of Problem	Type of Filter			
(1)	Cartridge (2)	Screen (3)	Centrifugal (4)	Media (5)
Flow range				
Low, <22.7 m^3/h	R[a/]	R	OK	R
Med., 22.7-113.6 m^3/h	NR[b/]	R	R	R
High, >113.6 m^3/h	NR	R	R	R
Inorganics				
Large particles, >550 μ (30 mesh)	OK[c/]	RX[d/]	OK	OKX[e/]
Med. particles, 74-550 μ (30-200 mesh)	OK	R	R	R
Small particles, <74 μ (200 mesh)	OK	NR	RX	R
Low concentrations, <10 mg/ℓ	OK	R	R	R
Med. concentrations, 10-100 mg/ℓ	NR	RX	R	R
High concentrations, >100 mg/ℓ	NR	RX	RX	RX
Organics				
Low concentrations, <10 mg/ℓ	OK	OK	RX	R
High concentrations, >10 mg/ℓ	NR	NR	NR	OKX

a/ R=Suitable filtration units are available.
b/ NR=Not recommended in most situations.
c/ OK=Suitable filtration units are available, but may not be ideal.
d/ RX=Recommend that two types of filtration units be used in series.
e/ OKX=Recommend that pre-screening be used.

Designers should always provide for flushing mains, submains, and lateral lines. All lines need to be thoroughly flushed immediately after installation, and mains and submains should be flushed before laterals are connected. Whenever possible, emitters should be placed on the top of the tubing for both surface and subsurface systems to prevent suspended materials from entering the emitters. Backflow prevention devices should also be installed to prevent contamination of water sources. For drip systems located on undulating terrain, air and/or vacuum relief valves should be installed at the control station (pumps, filters, time clocks, etc.) as well as at the highest points.

A chemical injector and water meter should also be integral parts of drip design. Two chemical injection points should be provided--one before and one after the main filter. This optional feature allows the chemical solution to by-pass the filter when filtering is not required and helps to prevent corrosion of valves, filter screens, and sand media filters. In all cases, the injection line should be equipped with a small in-line hose filter or screen. Injection points should be positioned so that adequate mixing of the injected fertilizers occurs before flow divides in several directions (18). The importance of having a water measurement device on every drip system has often been overlooked. A water meter is needed to check initial designs, to monitor maintenance problems, and to manage or schedule irrigations (6).

A listing of key design and installation suggestions follows:

1. Lateral lines should run on the flat, downhill, or along the contour.
2. Lateral lines of 13-to-15-mm (0.5-to-0.6-in) diameter should be less than 150 m (500 ft) for tree and vineyard crops and less than 200 m (660 ft) for row crops.
3. Submain length should not be more than 200 m (660 ft) and in some cases 100 m (330 ft).
4. System capacity must meet peak crop evapotranspiration requirements.
5. Filtration units must meet flow capacity and water quality.
6. Flushing valves should be installed at the ends of mains, submains, and lateral lines.
7. Emitters should face upward along lateral lines whenever possible.
8. A backflow prevention device should be installed after the pump or well.
9. Air or vacuum relief valves should be installed where needed.
10. Chemical injection points should be provided before and after the main filter.
11. A water meter should be included in the design.

MAINTENANCE

The primary goal of a maintenance schedule is to control emitter clogging to assure an economical life for a drip system. A maintenance schedule varies with water quality, depending on three factors: (1) physical--the suspended inorganic (sand, silt, and clay) and organic materials and plastic particles; (2) chemical--the precipitation of calcium or magnesium carbonate, calcium sulfate, heavy metal hydroxides, and some fertilizers; and (3) biological--the bacterial and algal filaments, slimes, and microbial-chemical deposits. A tentative water classification system is shown in Table 2 where the major physical, chemical, and biological factors are rated in terms of minor, moderate, or severe maintenance requirements.

Table 2. Simplified classification system for indicating maintenance requirements with drip irrigation systems (4).

Type of problem (1)	Minor (2)	Moderate (3)	Severe (4)
Physical			
Suspended solids, mg/ℓ	50	50-100	>100
Chemical			
pH	7.0	7.0-8.0	>8.0
Dissolved solids, mg/ℓ	500	500-2,000	>2,000
Manganese, mg/ℓ	0.1	0.1-1.5	>1.5
Total iron, mg/ℓ	0.2	0.2-1.5	>1.5
Hydrogen sulfide, mg/ℓ	0.2	0.2-2.0	>2.0
Biological			
Bacterial populations, counts/mℓ	10,000	10,000-50,000	>50,000

Preventive maintenance includes water filtration, field inspection, pipeline flushing, and chemical water treatment. Filters should be cleaned or backwashed, either automatically or manually, at least weekly. Where filters require more than daily attention, an automatic backflushing system should be added. Large variations in water quality can occur, and if a filtration unit requires cleaning every hour or two, we recommend discontinuing operations until water quality improves.

Systematic field inspection of emitters, pipelines, and accessory equipment is required to detect malfunctions before they become major failures. Chemical injectors, time clocks, pressure regulators, water meters, and main pump should be checked at least weekly. Water meters are useful for indicating pressure regulation problems, pipeline leaks, or clogged emitters. By dividing the accumulated flow by the operation time, the operator can determine the system flow rate. When this rate changes more than 10 percent, the system should be thoroughly inspected (5). Even when no field problems are indicated, a monthly field inspection should be made to check the emitters and drip lines.

Pipeline flushing, either automatically or manually, can be helpful where irrigation water is high in silt, clay, or biological residues (16, 19). Drip lateral lines should be flushed at least once every six months for tree crops and at the beginning, middle, and end of each season for row crops (5). A minimum flow velocity of 0.3 m/sec (1 ft/sec) is needed for flushing lateral lines (19).

Chemical water treatment is used when the chemical or biological hazards are moderate or severe (Table 2). Sulfuric and hydrochloric acid are commonly used to reduce chemical precipitation. With continuous acid treatment, carbonate precipitation can be prevented; and further, if precipitation has already started, carbonates can be dissolved, assuming that the acid-treated water can make contact with the precipitated material. The amount of acid addition needed to lower the pH is based on the acid titration of the water. For waters having a pH above 7.5, we generally recommend a final pH of 6 to 6.5.

Chlorination is often used to control biological problems in drip systems. The application principles of chlorination for drip irrigation is similar to that used in municipal, swimming pool, cooling tower, and wastewater treatment. The three basic chlorine sources are sodium hypochlorite (a liquid), calcium hypochlorite (a solid or powder), and chlorine gas. Since both sodium and calcium hypochlorite have an alkaline reaction with water, an acid may need to be added if the water is already alkaline. Chlorine gas, on the other hand, produces an acid reaction with water so that acid additions may not be necessary; but the extent of pH lowering will depend upon the amount of chlorine gas added and the buffering capacity of the water. Test kits are available to specifically measure "free residual chlorine" which is the primary bactericidal agent. Most pathogenic bacteria and viruses are inactivated at a free residual chlorine concentration of about 1 mg/ℓ with contact time of 10 to 30 minutes.

Acids and chlorine compounds should be stored separately, preferably in plastic or fiberglass storage tanks. All chemicals, and diluted solutions as well, should be stored in a secure place. In preparing dilutions, concentrated stock of acid or other chemicals should be added to the water and not vice-versa. A convenient water source should be provided near the chemical tank and injector for washing off any chemicals that may contact the skin. Protective goggles, face shields, and clothing should also be worn when making chemical dilutions. Where gas chlorinators are used, safety devices should be installed and routinely inspected for proper operation.

A summary of maintenance requirements follows:

1. Filters should be cleaned or backwashed at least two or three times per week and inspected at least weekly.
2. Automatic flushing devices should be used where the water is high in silt and clay.
3. Chemical injectors, time clocks, pressure regulators, water meters, and main pump should be checked at least weekly.
4. Field inspections for malfunctioning emitters and pipeline leaks will be required at least monthly (sometimes weekly).
5. Flush lateral lines by hand every six months for tree crops, or at least three times per season for row crops.
6. Chemical water treatment is needed when the chemical or biological hazards are moderate or severe.
7. Inject only approved or tested chemicals. system.
8. Follow safety requirements for injecting chemicals.

MANAGEMENT

The purpose of a total management scheme is to insure optimum crop response. Water meters for checking application and system operation should be read at least two or three times a week. Drip systems can be readily automated to save labor by using single and multi-station timers or controllers plus related solenoid valves to turn the water on or off. Future drip systems will involve microprocessors that can monitor not only soil moisture, but also hydraulic pressure, flow rate, chemical injection rate, water quality, and climatic conditions. Records of water application amounts and times should be kept to insure maximum efficiency from the system.

A decrease in the irrigation water requirement or increase in crop yield from drip compared with another method will come from an improvement in the on-farm irrigation efficiency. On-farm efficiency refers to the ratio of the irrigation water requirement to the total quantity of water delivered to the field (expressed as a percentage). On-farm efficiency for drip irrigation can theoretically approach 90-95 percent. The irrigation water requirement is the net amount of water that can be supplied by irrigation to satisfy crop ET, leaching of salts, and miscellaneous water requirements that are not provided by water storage in the soil or by precipitation that enters the soil (14). Some of the miscellaneous water requirements include essential watering for germination and emergence, frost protection, wind erosion protection, plant cooling, and maintenance of harvest quality. Since a drip system lends itself to the application of small quantities of water, minimal water applications can be made to provide for these miscellaneous water requirements. In our opinion, however, many growers have under-applied water so that adequate soil water storage is not available prior to the peak ET rate. Once water applications fall behind plant use, a drip system may not have the capacity to replenish the soil moisture deficit. Therefore, a grower should check the soil water penetration and storage regularly, particularly during the mid-season crop development stages.

Irrigation scheduling involves two decisions: (1) how much to apply, and (2) how often to apply. We have conducted investigations on six crops to help answer these questions. Where both irrigation amount and frequency were varied, the highest production with drip irrigation occurred at seasonal water applications nearly equal to or slightly greater than measured ET under furrow irrigation (6). We have also found that water applications do not have to be made daily over the entire growing season nor for every cropping situation (6). Possible reasons for applying drip irrigations on other than a daily schedule include the need for sufficient water penetration with a deep-rooted crop, improving aeration in the effective crop root zone on a fine-textured soil, and moving salts further away from the plant. Although the optimum irrigation frequency will depend on the type of crop, soil, and water quality, a manager has the flexibility of being able to apply daily drip irrigations during the hotter months and to decrease to a weekly schedule. On the other hand, frequent trickle irrigations can be particularly beneficial during germination for most water qualities and during the peak development of the crop for high salinity waters (2, 12, 20).

Fertilizers and other water amendments (herbicides, insecticides, fungicides, etc.) applied through drip systems can also improve efficiency, save labor, and increase flexibility in scheduling of applications to fit crop needs. Crop response to fertilizer applications by the drip method has been excellent, but limited information is available on the drip application of herbicides, insecticides, or fungicides. Some growers have overlooked the fact that fertilizer applications may need to be frequent, either weekly or bi-weekly, to insure that adequate nutrients are in the plant root zone during all stages of plant growth.

Methods for improving cultural practices to match the drip irrigation concept have not been fully explored. More hedge plantings for tree crops, higher or variable plant populations for row crops, and increased use of natural or synthetic mulches with drip systems on conventional crops are examples of possible practices to be tested. In some cases, equipment has been developed for mechanized installation and retrieval of drip systems; minimum tillage is being tried with drip systems; and continuous cultural operations such as spraying, weeding, thinning, and harvesting are possible without interrupting the drip irrigation cycle.

A listing of the key management suggestions follows:

1. Water measurement is an important tool in irrigation scheduling.
2. Automation can save labor in the application of water and fertilizer.
3. Soil water penetration and storage should be checked regularly.
4. Use as many field measurements as possible to assist in irrigation scheduling.
5. Irrigation water applications should closely match the crop evapotranspiration rate.
6. Irrigation frequency can be flexible for many soil, water, crop conditions.
7. More frequent irrigations can be helpful with salinity management.
8. Fertilizer applications will need to be weekly or biweekly during the early stages of plant growth.
9. Cultural practices will need to be modified where drip systems are used.

SUMMARY

Drip/trickle irrigation use on various crops continues to expand; however, before success can be assured, potential problems must be recognized and reduced by proper design, installation, maintenance, and management. Design and installation can be improved by shortening lengths of lateral lines, by providing system capacity to meet peak evapotranspiration rates, and by selecting the correct filtration unit. Preventive maintenance can be enhanced by following guidelines for water filtration, pipeline flushing, field inspection, and chemical water treatment. Management can be simplified by taking water application measurements, by monitoring soil, plant, and atmospheric conditions, and by matching cultural practices to the drip irrigation operation.

REFERENCES

1. Baars, I. C., Design of Trickle Irrigation Systems. Agricultural Univ., Wageningen, The Netherlands, 1976, 106 pp.

2. Bernstein, L., and Francois, L. E., "Comparison of Drip, Furrow, and Sprinkler Irrigation," Soil Science, Vol. 115, No. 1, Jan. 1973, pp. 73-76.
3. Bralts, V. F., Wu, I. P., and Gitlin, H. M., "Manufacturing Variation and Drip Irrigation Uniformity," Transactions of the American Society of Agricultural Engineers, Vol. 24, No. 1, Jan.-Feb. 1981, pp. 113-119.
4. Bucks, D. A., and Nakayama, F. S., "Injection of fertilizer and Other Chemicals for Drip Irrigation, Total Irrigation--Show and Tell, Proceedings of the Irrigation Association Agri-Turf Conference, Houston, Texas, Feb. 1980, pp. 166-180.
5. Bucks, D. A., Nakayama, F. S., and Gilbert, R. G., "Trickle Irrigation Water Quality and Preventive Maintenance," Agricultural Water Management, Vol. 2, No. 2, Jun. 1979, pp. 149-162.
6. Bucks, D. A., Nakayama, F. S., and Warrick, A. W., "Principles, Practices, and Potentialities of Trickle (Drip) Irrigation, In Advances in Irrigation, Vol. 1, D. Hillel, ed., Academic Press, New York, NY, 1982, pp. 219-298.
7. Bucks, D. A., Erie, L. J., French, O. F., Nakayama, F. S., and Pew, W. D., "Subsurface Trickle Irrigation Management with Multiple Cropping," Transactions of the American Society of Agricultural Engineers, Vol. 24, No. 6, Nov.-Dec. 1981, pp. 1482-1492.
8. Burman, R. D., Nixon, P. R., Wright, J. L., and Pruitt, W. O., "Water Requirements," In Design and Operation of Farm Irrigation Systems, M. E. Jensen, ed, American Society of Agricultural Engineers, St. Joseph, Michigan, 1980, pp. 189-232.
9. Doorenbos, J., and Pruitt, W. O., "Crop Water Requirements," Irrigation and Drainage Paper 24, Food and Agricultural Organization of the United Nations, Rome, Italy, 1977, 156 pp.
10. Erie, L. J., French, O. F., Bucks, D. A., and Harris, K., "Consumptive Use of Water by Major Crops in the Southwestern United States," Conservation Research Report 29, United States Department of Agriculture, Washington, DC, 1981, 42 pp.
11. Gilbert, R. G., Nakayama, F. S., Bucks, D. A., French, O. F., and Adamson, K. C., "Trickle Irrigation: Emitter Clogging and Flow Problems," Agricultural Water Management, Vol. 3, No. 3, Dec. 1981, pp. 159-178.
12. Gornat, B., Goldberg, D., Rimon, D., and Ben-Asher, J., "The Physiological Effects of Water Quality and Methods of Application on Tomato, Cucumber, and Pepper," Journal American Society Horticulture Science, Vol. 98, No. 2, Mar. 1973, pp. 202-205.
13. Howell, T. A., Stevenson, D. S., Aljibury, F. F., Gitlin, H. M., Wu, I. P., Warrick, A. W., and Roots, P. A. C., "Design and Operation of Trickle (drip) systems," In Design and Operation of Farm Irrigation Systems, M. E. Jensen, ed., American Society of Agricultural Engineers, St. Joseph, Michigan, 1980, pp. 663-717.
14. Jensen, M. E., ed, "Consumptive Use of Water and Irrigation Water Requirements," Report by the Technical Committee on Irrigation Water Requirements of the Irrigation and Drainage Division, ASCE, 1973, 227 pp.
15. Keller, J., and Karmeli, D., Trickle Irrigation Design, 1st ed., RainBird Sprinkler Manufacturing Corp., Glendora, California, 1975, 133 pp.

16. McElhoe, B. A., and Milton, H. W., "Chemical Treatment of Drip Irrigation Water," Proceedings of the 2nd International Drip Irrigation Congress, 1974, pp. 215-220.
17. Nakayama, F. S., and Bucks, D. A., "Emitter Clogging Effects on Trickle Irrigation Uniformity," Transactions of the American Society of Agricultural Engineers, Vol. 24, No. 1, Jan.-Feb. 1981, pp. 77-80.
18. Rolston, D. E., Rauschkolb, R. S., Phene, C. J., Miller, R. J., Uriu, K., Carlson, R. M., and Henderson, D. W., "Applying Nutrients and Other Chemicals to Trickle-Irrigated Crops," Cooperative Extension Bulletin 1893, University of California, Berkeley, 1979, 14 pp.
19. Shearer, M. N., "Minimum Screening and Automatic Flushing," Proceedings of the 4th Annual International Drip Irrigation Association Meeting, 1977, pp. 32-36.
20. Tscheschke, P., Alfaro, J. F., Keller, J., and Hanks, R. J., "Trickle Irrigated Soil Water Potential as Influenced by Management of Highly Saline Water," Soil Science, Vol. 117, No. 4, Apr. 1974, pp. 226-231.
21. Wu, I. P., Howell, T. A., and Hiler, E. A., "Hydraulic Design of Drip Irrigation Systems," Hawaii Agricultural Experiment Station Technical Bulletin 109, University of Hawaii, Honolulu, Hawaii, 1979, 80 pp.

Augmentation of Groundwater Resources by Effluents Injection into saline Aquifers

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ABSTRACT: This study concerns the development of simulation methods for effluents injection into saline aquifers. A simplified model of the aquifer is considered being consisting of saline layer on top of which a layer saturated with fresh water is located. The latter is subject to growth due to the effluents injection. Between the saline and fresh water zones a transition zone, similar to a boundary layer, develops. In this study finite difference iterative schemes are developed and used for the simulation of various alternatives for the management of groundwater system. The methods of simulation suggested in this study predict variations in the salinity distribution as well as build-up of pressures in the aquifer. They are subject to strict criteria of accuracy and convergence created by the basic laws of conservation. These methods are found to be very stable, with very good convergence and consume small quantities of computer time and memory.

INTRODUCTION

Various publications (e.g. Refs.2,3 and 4) consider the possibilities of treated effluents injection into saline aquifers. In certain cases the injected effluents can be considered as possible groundwater resources being useful in the future. Effluents injection is also considered for the reclamation of aquifers subject to salinization processes due to intensive utilization. The objective of this study is to develop simplified numerical models by which all physical phenomena taking place in the aquifer due to effluents injection can be simulated. For the simulation we refer to an aquifer originally consisting of two layers, of which the deeper one is saturated with saline water, the other one is saturated with fresh water. The latter expands due to the effluents injection. Between the saline and fresh water zones a transition zone similar to a boundary layer develops (Refs. 7,8).

BASIC EQUATIONS AND STATEMENT OF THE PROBLEM

The basic equations being used for the simulation of the stratified flow created in the aquifer are the equations of continuity, motion, solute transport, and the equation of state represented respectively as follows:

$$\nabla \cdot \vec{q} + \frac{\partial n}{\partial t} = 0 \qquad (1)$$

$$\nabla p - \rho \vec{g} + \frac{\mu}{k} \vec{q} = 0 \qquad (2)$$

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