CHAPTER - 2

LITERATURE REVIEW

2.1 General

This chapter deals with literature review. Research papers are categorized as per various components of micro irrigation system like microtubes, lateral, manifold, submain, main and hydraulics of these components. Research papers on case studies are also referred.

2.2 Literature Review

Indigenous Technical Know-how Micro Irrigation System (ITK MIS) consists of main, sub main, manifold, laterals, poly tube, micro manifold and micro tube. As related to the topic of study, numerous research papers have been reviewed from various international and national journals, proceedings of symposiums, seminars and conferences.

To evolve design criteria of the newly developed system related to cost effectiveness, hydraulics and yield response, the literature reviewed is categorized as following:

(1) Microtubes
(2) Laterals
(3) Manifold
(4) Main/sub main
(5) Low cost technology
(6) Case studies
(7) Crops

2.2.1 Microtubes

(a) The pressure discharge relationship of different diameter microtubes is expressed in power form equation. The value of an exponent equation has little variation compared to multiplying constant for various length and diameter microtubes. A common power form equation is developed by Srivastava et al. (1993) showing relationship among discharge rate, tube diameter, tube length and pressure head. The surface horizontal movement of the water is also expressed in power form, as a function of system parameters and time of application. The surface horizontal movement of water front under microtube drip system increased with increase in diameter and application time, for given pressure head and decreased with increase in tube length.

(b) The experiment was carried out by Deshmukh et al. (2004) to study the hydraulics of micro tube trickle irrigation system with objective to furnish the information on the optimum length of lateral (16 mm) and discharge of micro tube (1.2 mm) corresponding to different lengths and spacing of micro tube under different operating pressures. The ready reckoners, nomographs and equations have been developed for predicting optimum length of lateral and discharge of micro tube with respect to different micro tube lengths (50, 100, 150 and 200 cm), operating pressures (0.6, 0.8, 1.0 and 1.2 kg/cm^2) and micro tube spacing (1.5 and 3.0 m). It was found that optimum length of lateral (L), increases with increase in microtube length (L_m) or operating pressure (P2) or micro tube spacing (Sm) along lateral.

The prediction equation for optimum length of lateral has been developed as,

$$L = -21.15 + 0.105\, L_m + 19.125\, P2 + 20\, Sm \quad (R^2 = 0.969) \ldots \qquad (2.1)$$

It was observed that discharge of microtube (q_i) decreases with increase in micro tube length and it increases with increase in operating pressure or micro tube spacing along lateral.

The prediction equation for discharge of micro tube has been developed as,

$$q_i = 5.41 - 0.0367\ L_m + 7.075\ P2 + 0.8592\ Sm\ (R^2 = 0.919) \ldots \quad (2.2)$$

The ready reckoners, nomographs and prediction equations may be used as perfect and reliable design tool for predicting optimum length of lateral and discharge of micro tube corresponding to different micro tube lengths, operating pressures and micro tube spacing along lateral; while designing micro tube trickle irrigation system, by designers and planners.

(c) Hydraulics of micro tube trickle irrigation system was studied to develop ready reckoners and equations for predicting optimum length of lateral (16 mm diameter) and discharge of micro tube (1.2 mm diameter) corresponding to different micro tube lengths (50, 100, 150 and 200 cm) and spacing of micro tube (1.5 and 3.0 m) under different operating pressures (0.6, 0.8, 1.0 and 1.2 kg/cm^2).

Deshmukh et al. (2005) found that optimum length of lateral, increases with increase in microtube length or operating pressure or micro tube spacing along lateral. The prediction equation for optimum length of lateral has been developed by regression analysis.

It was observed that discharge of microtube decreases with increase in microtube length and it increases with increase in operating pressure or microtube spacing along lateral. The prediction equation for discharge of micro tube has been developed by regression analysis.
Designers and planners may use the ready reckoners and prediction equations as perfect and reliable design tool for designing of micro tube trickle irrigation system.

(d) The microtube is a simple and cheap emitter that was widely used throughout the world in the early days of drip irrigation. Its length can be adjusted according to the pressure distribution along the lateral line and discharge from the microtube can be adjusted by its length. This not only counters the pressure loss due to pipe friction but also makes it suitable for undulating and hilly conditions, where pressure in the lateral line varies considerably according to the differences in the elevation. This is the major problem facing the designer, i.e. emitter flow changes as acting pressure head changes. Almeida et al. (2009), proposed a novel micro-sprinkler system that uses micro tubes as the emitter and where the length of microtube can be varied in response to pressure changes along the lateral to give uniformity of emitter discharges. The objective of this work is to develop and validate empirical and semi-theoretical equations for the emitter hydraulics. Laboratory testing of two microtube emitters of different diameter over a range of pressure & discharges was used in the development of the equations relating pressure and discharge, and pressure and length for these emitters. The equations proposed will be used in the design of the microsprinkler system, to determine the length of microtube required to give the nominal discharge for any given pressure. The semi-theoretical approach underlined the importance of accurate measurement of the microtube diameter and the uncertainty in the estimation of the friction factor for these tubes.

2.2.2 Lateral

(a) The Darcy-Weisbach equation is fundamentally correct than other empirical and approximate equations but pipeline engineers most commonly use the Hazen-William equation due to its computational simplicity. Different empirical equations give significantly different estimates of frictional head losses depending on pipe size and rate of flow. Hydraulic friction loss in pipelines directly affects pipe and pump sizes, as well as hydraulic balance of the network.

Mohan and Sahoo (1991) presented analytical and graphical methods to determine the magnitude of such computed head loss differences. The empirical equations are modified to give accurate estimates of friction loss as that of Darcy-Weisbach equation for different flow rates and diameter ranges most often encountered in irrigation and municipal pipe networks.

(b) Ojha and Subbaiah (1997) studied diversion of flow through a lateral slot. It is analyzed using the spatially varied flow equation and the elementary discharge coefficient function. The implications of treating flow through a side slot as through a small orifice, as reported in the literature, are also studied. For different combinations of slot openings and sill heights, data for a set of 110 runs have been obtained. Using these experimental observations, equations for the elementary discharge coefficient are obtained for small as well as large orifice formulation of flow through a lateral slot.

The elementary discharge coefficient is mainly dependent on slot geometry. Using the developed expressions of the elementary discharge coefficient, it is shown that more than 90% are represented within an error band of 10% plus and minus. Within the range of data collected, the discharge coefficient is found to be a strongly dependent on lateral slot dimensions. The use of the large orifice formulation is advocated over the small orifice formulation.

(c) Anwar (1999) derived a factor *G* for pipelines with equally spaced multiple outlets and outflow at the downstream end. The proposed factor is a function of the number of outlets along the pipeline and also a function of the friction formula used. Factor *G* allows head loss in such pipelines to be computed directly provided the first outlet is one outlet spacing distance from the pipeline inlet. Under conditions of zero out flow at the downstream end of the pipeline, factor *G* reduces to the well-known Christiansen's factor *F*. Factor *G* allows the design of segments of pipelines with multiple outlets. It may find application with irrigation engineers in designing sprinkler and trickle irrigation laterals and manifolds with multiple-diameter sizes. It also may be used in trickle line hydraulics in flushing mode.

This research presents factor G as a sequel to the well known and widely used Christiansen's factor F for direct computation of head loss caused by friction in a pipeline with multiple equally spaced outlets. Factor G is a more generalized form of factor F in that it allows for outflow at the downstream end of the pipeline beyond the last outlet. If, for a particular case, the outflow at the downstream end is set to zero, then factor G reduces to factor F. Factor G can be used for calculating head loss caused by friction in pipelines with outlets and multiple diameters. Application of factor G has been demonstrated with a worked example. When a friction formula such as the Darcy- Weisbach equation is used, in which the exponent of the velocity (or discharge) term is 2.00, factor G can be used with high precision. A slight error is introduced when a friction formula such as the Hazen-Williams equation is used where the exponent of the velocity term is less than 2.00, because of an inherent assumption in the expansion of the summation function in the Euler-Maclaurin summation formula.

(d) Anwar (2000) presented analytical equations for two average pressure correction factors developed for linear displacement laterals with or without outflow at the downstream end. The average correction factor for laterals without downstream outflow, when applied to a relatively large number of outlets is in good agreement with earlier work. For a relatively small number of outlets, the average correction factor presented is more accurate. The average correction factor for laterals with outflow reduces to that for laterals without outflow when the outflow ratio is reduced to zero. For a relatively large number of outlets, this average correction factor is primarily a function of the outflow ratio. For both large outflow ratios and large outlet numbers, the average correction factor is almost a constant. To apply the average correction factor to design a tapered lateral, an expression relating lateral inlet head to required average head and friction head loss has been developed. The expression can be applied to a lateral with any number of reaches with different diameters.

(e) A new approach for solving lateral hydraulic problems in laminar or turbulent flow based on a successive approximations scheme is developed by Vallesquino and Luque-Escamilla (2001). The outflow is treated as a discrete variable event by means of Taylor polynomials used to calculate flow rates along the lateral (minimal outflow included). The friction head losses are calculated using the Darcy-Weisbach equation with a non constant logarithmic friction factor *f*. This algorithm allows hydraulic computation for a set of connected laterals (with different pipeline diameter, slope, flow regime, or emitter spacing) if a residual outflow *Qr* is used. The new approach can be used to calculate flow variation on laterals and submains in trickle or sprinkler irrigation systems without an excessive calculation effort. Results are comparable to those obtained in the literature.

(f) Previous continuous-uniform outlet discharge approaches for the hydraulic analysis of irrigation laterals are generally valid for large (theoretically) infinite number of outlets. For a finite number of outlets, however, these approaches may lead to errors in hydraulic computation. A new continuous-uniform outflow approach that takes into account the effect of the number of outlets on the lateral hydraulics is presented.

Valiantzas (2002a) presented a new analytical equation describing the energy line shape along uniform sprinkle and trickle irrigation laterals and manifolds. The effect of ground slope and velocity head on hydraulic computation is also considered. The method is however restricted by the simplified assumption of equal outlet discharge. An alternate improved analytical method considering the effect of non-uniform outflow distribution along the lateral is also included. Analytical expressions for determining the inlet pressure head and global statistical parameters characterizing the outflow distribution (Christiansen uniformity coefficient, pressure head variation) are developed for design and evaluation purposes. Comparison tests with an accurate numerical stepwise method indicated that the proposed simplified approach is more accurate than other previous works particularly when the number of outlets is relatively small.

(g) Jain et al. (2002) developed a simple and accurate method for designing single, paired, and tapered micro irrigation laterals. The hydraulics of the lateral is evaluated using a lateral discharge equation approach. A simple power equation is used to express the relationship between the inlet flow rate and inlet pressure head of the lateral. Keeping the flow variation within the specified limit, a procedure for designing the length of the tapered section is developed. The lateral is designed using a step-by-step method. The length of the tapered section is determined by the golden section search method. The lateral discharge equation presented by Kang and Nishiyama (1996a) for designing micro irrigation laterals may result in severe error when extrapolated beyond the selected range of pressure heads at the downstream end of the lateral. The error is generally encountered in the case of long laterals where it is difficult to guess the pressure head range at the downstream end. Use of a simple power equation as the lateral discharge equation can eliminate such error. The lateral discharge equation proposed has been found to be equally accurate. In large micro irrigation systems the cost can be reduced to some extent by using tapered (two-pipe-size) laterals. A procedure for designing tapered laterals using the lateral discharge equation approach has been presented.

(h) A new analytical continuous-uniform outflow approach that takes into account the effect of the number of outlets on the multi diameter lateral hydraulics is presented by Valiantzas (2002b). The pressure head profile along the multi diameter pipeline is described by a simple analytical function providing direct calculation of the outlet pressure head along the pipeline. The method is significantly improved by introducing an adjusted spatially variable outflow equation of power function form for the errors caused by the assumption of equal outlet discharge. The effect of ground slope on hydraulic computation is also considered. Simple equations are derived for the direct calculation of the maximum, minimum, and inlet pressure head along the multi diameter pipeline. The optimum design problem for two-diameter laterals is also solved analytically. For specified total length of a two-diameter pipeline, a simple algebraic equation is derived to calculate directly the appropriate lengths of the reaches of different diameters in such a way that the total cost of the pipeline is minimized. Comparison tests with an accurate numerical stepwise method indicate that the proposed analytical approach is sufficiently accurate.

(i) Vallesquino and Luque-Escamilla (2002) presented a simplified method for the resolution of lateral hydraulic problems in laminar and turbulent flow.

In the first stage, the head losses are calculated by applying the Darcy–Weisbach equation with a discrete and constant outflow model, which leads to a correction parameter equivalent to Anwar's G factor. The difficulty that arises from variation of the friction factor along the lateral (due to discharge flow) is overcome by means of an equivalent friction factor. In the second stage, this head loss model is used together with a variable discharge model based on Taylor polynomials to make a better estimate of the flow rate distribution by means of a successive-approximations scheme. This new approach directly allows the computation of the real mean lateral's outflow and the minimum and maximum discharges. The method proposed is useful to work out the hydraulic computation of laterals with the inlet segment at full or fractional outlet spacing, and complex laterals when a different pipeline diameter, slope, flow regime, or emitter gap has to be considered. The results are comparable to those obtained in the literature. A simplified approach based on a successive-approximations scheme was developed for solving the lateral hydraulics problem in laminar and turbulent flow.

(j) Minor head losses at emitter insertions along drip laterals were predicted by a derivation of Be´langer's theorem and analyzed by the classic formula that includes a friction coefficient k multiplied by a kinetic energy term. Juana et al (2002a) established a relationship for k as a function of some emitter geometric characteristics. These take into account the flow expansion behind the reduction of the cross-sectional area of the pipe due to obstruction by the emitter. Flow constrictions at emitter insertions were estimated by analogy with contraction produced by water jets discharging through orifices. An experimental procedure was also developed to determine minor losses in situ, in the laboratory or in the field. An approach is suggested to calculate either k or the emitter equivalent length *le* as a function of lateral head losses, inlet head, and flow rate. Internal diameter and length of lateral, emitter spacing, emitter discharge equation, and water viscosity must be known. Approximate analytical relations to study flow in laterals were developed. They may be used to design and evaluate drip irrigation units. Analytical and experimental procedures are validated in the companion paper by Juana et al.(2002b)

Values of friction coefficient K and equivalent length l_e suggested by Juana et al. (2002a) were determined for various emitter models using analytical and experimental procedures developed in the companion paper by Juana et al. (2002b). Flow contraction coefficient Cc for water jets discharging through orifices with angle $\alpha = 45°$ is suggested when the emitters have hydrodynamic geometry at the insertion. Otherwise, $\alpha = 90°$or, as an extreme value, $\alpha = 180°$ is preferred. Both criteria K and l_e showed a reasonable agreement for minor losses evaluation produced at emitter insertions along drip laterals. Accuracy on their determination was analyzed. Larger dispersion of K and l_e values was observed when lateral head losses were small. Inlet head, Reynolds number, and emitter spacing did not show a clear effect on K and l_e values, whereas the effect of obstruction ratio r of the pipe cross-sectional area at the emitter location was of practical significance. Parameters of the emitter discharge equation determined with lateral tests were comparable to those obtained on an emitter testing bench using the International Standard procedure.

Predicted values of friction coefficient K and equivalent length l_e showed good approximations to those observed experimentally. Both parameters were analyzed as a function of the obstruction ratio r of the pipe cross-sectional area at emitter insertion and of a flow constriction coefficient Cc. Values of the latter were estimated using flow constriction data from water jets discharging through orifices, and observed results showed an agreement with calculations. The effect of emitter spacing, inlet pressure, and Reynolds number on K and le values were of no practical significance. This reinforces the effect of ratio r which, in turn, simplifies the determination of K and le parameters. Also, it suggests the validity of practical decisions when experimental data are not available.

(k) Statistical uniformity of discharge variation is an important parameter in designing drip irrigation laterals. A simple equation is derived by Ravikumar et al. (2003) to determine the coefficient of variation of discharge. This equation is used to determine the coefficient of variation of discharge for a numerical problem. The result is compared with the energy gradient line approach. Both the methods give the same result.

For any required coefficient of variation of discharge, the diameter of a lateral can be designed directly for a known lateral length, slope, emitter discharge exponent, pressure head at the start of the lateral, and discharge rate through the lateral, by writing the analytical equation in quadratic form.

(l) Mahar and Singh (2003) derived expressions for the factor K to relate the total frictional head loss, average outlet operating pressure head, and the inlet pressure head of a multi outlet pipeline. In the developed expressions, the factor K is a function of the number of outlets on different pipe diameters, combination of diameters, and position of the first outlet from the inlet. Values of the factor K obtained from the developed expressions are compared with constant values being taken as per existing practice. The comparison suggests using the developed expressions for accurate computation of the factor K for multi outlet pipelines especially comprising of two or more diameters.

Based on this study, they concluded that the existing practice of taking a constant value of the factor K may over or under estimate the inlet pressure head. For proper design of multi outlet pipelines, the developed expressions can be used to compute the accurate values of the factor K.

For single-diameter multi outlet pipelines, the factor K is affected by the position of the first outlet from the inlet and the number of outlets and for multi diameter multi outlet pipelines, the factor K widely varies with the combination of diameters having different number of outlets.

(m) A simplified analytical solution that takes into account the effect of the emitter discharge exponent on the hydraulic computations of tapered micro irrigation laterals is presented by Yildirim and Agiralioglu (2004a). The hydraulic analysis is evaluated based on the spatially variable discharge function approach. A simple power equation was used to express distribution of the variable outflow delivered from the each emitter along the lateral. An analytical solution is developed for the case of a linear relationship between the emitter discharge and pressure head, namely, the emitter discharge exponent equals to unique. In this procedure, the analytical derivations can be applied for uphill, downhill, and zero slope conditions. Results are comparable to those obtained from the literature.

(n) Approximate analytical expressions were obtained by Juana et al. (2004), which relate uniformity indices of water distribution in rectangular drip irrigation units as a function of the variables that define that unit: lengths and diameters of laterals and submain, spacing of emitters and laterals, ground slopes, parameters of the emitter discharge equation, and equivalent lengths characterizing local losses. The proposed expressions offer greater precision than might be needed in irrigation practice. They do not require iterative calculations and improve the procedures normally used. They may be useful in the design of drip irrigation units and in their evaluation and management.

(o) Selection of right size pipeline is an important issue in the design of pressurized irrigation systems. Consideration of both hydraulic aspects and economic parameters is an important issue in the developing any model equation. Reddy and Tiwari (2004) developed a model equation for selecting an economical pipe size using life-costing technique. Critical flow criterion was used as the basis for change of pipe diameters. Capital Recovery Factor (CRF) was used as economic parameter for estimating annual costs. The model equation for different flow regimes was developed using both Darcy-Weishbach (DW) and Hazen-Williams (HW) equations and suitable friction factors. A computer software program was developed for solving the equations and to estimate critical flows. Critical flow rates were estimated from the developed equation for commonly used trickle submain and main pipe sizes. A detailed sensitivity analysis was performed to study the effect of various design parameters on critical flows. The developed approach can be incorporated in the computer programs and software developments for determining economic pipe sizes.

(p) The hydraulic design of a lateral or a sub -main unit in a micro irrigation system has been a problem tackled by many authors. In applications of previous analytical approaches for trickle lateral hydraulic computation, it is generally assumed that the emitter outflow along the lateral is constant. However, significant deviations from accurate numerical solutions in hydraulic analysis could be caused by this basic assumption of constant emitter outflow. Recently, some alternative analytical methods with more accurate results were developed based on the spatially variable outflow approach. A comparison test was applied to the seven design examples with the special limited design conditions of some calculation methods, such as emitter discharge exponent, to cover various combinations of irrigation parameters, varying emitter discharge exponents, and different ground slope conditions. The results were shown graphically in dimensionless form. These figures could also be used as design charts in practice.

In this study, Yildirim and Agiralioglu (2004b) considered seven calculation methods for the lateral hydraulic design and these were clearly analyzed and classified for comparative purposes from points of view such as solution methods, basic assumptions, formulations used, and differences in application. In addition, these were compared and evaluated to cover various combinations of irrigation parameters, for the varying emitter discharge exponents and different ground slope conditions. The comparison test was applied for the seven design examples with special limited design conditions such as emitter discharge exponent, and the results were shown graphically in dimensionless form, for practical purposes.

(q) The accurate design of drip irrigation laterals needs to consider the variation of hydraulic head due to pipe elevation changes, head losses along the lines, and also, at a given operating pressure, emitter discharge variations related to manufacturing variability, clogging, and water temperature. Hydraulic head variations are consequent to both the friction losses and local losses due to the in-line or on-line emitters along the pipe, which determine the contraction and subsequent enlargement of the flow streamlines. Moreover, in-line emitters usually have a smaller diameter than the pipe, and therefore an additional friction loss must be considered. Evaluation of energy losses and consequently the design of drip irrigation lines is usually carried out by assuming the hypothesis that local losses can be neglected, even if previous experimental researches showed that local losses can become a significant percentage of total head loss as a consequence of the high number of emitters installed along the lines.

Provenzano and Pumo (2004) reported the results of an experimental investigation to evaluate local losses in integrated laterals in which co extruded emitters are installed inside the pipe. Local losses were measured for 10 different types of commercially available integrated laterals and for different Reynolds numbers. A practical power relationship was deduced between the ∝ coefficient, expressing the amount of local losses as a fraction of the kinetic head, and a simple geometric parameter characterizing the geometry of the emitter and the pipe. Local losses obtained for integrated laterals were then compared with those due to the on-line emitters, previously determined as a function of the pipe-emitter geometry. The proposed criterion for calculating the local losses was finally verified by using a step-by-step procedure.

(r) A test set up was developed by Bhandarkar et al. (2005) for determining the head loss due to barb protrusion into the different size of lateral pipes. Six dripper samples were selected for determining barb losses. The pressure data was generated for six dripper samples by operating the system in the pressure range of 50 to 120 kPa with an increment of 10kPa. The lateral flow rates were measured at each operating pressure by opening the valve full using volumetric method. Head loss due to barb connection was calculated for two sizes of 12 and16 mm lateral pipes at all flow rates.

The average head loss due to barb insertion into lateral pipes was found to have linear relationship with lateral pipe flow rate with regression co efficient of more than 0.90 for selected six dripper samples. The head loss increased with increase in the protrusion area .The average head loss due to barb connection was observed to be 0.065 m and 0.058m in 12 and 16 mm lateral sizes respectively at an average protrusion area of 20.73 mm^2.

(s) In previous analytical approaches, the direct calculation of friction loss along a lateral is usually based on empirical power form flow resistance equations, such as the Hazen–Williams and Blasius equations. The more generalized Darcy–Weisbach resistance equation is not usually applied since its friction coefficient varies along the lateral. Initially, the

Darcy–Weisbach and Hazen–Williams equations are systematically compared, leading to a correction form for the Hazen–Williams coefficient. In addition, a more accurate procedure assuming a power function form for the Darcy–Weisbach equation along irrigation laterals is also proposed by Valiantzas (2005).

The systematic analysis of various typical flow pipe irrigation situations, for example, sprinkler irrigation laterals of linear or radial-center pivot displacement, trickle irrigation laterals, and manifolds! indicates that the friction loss along laterals calculated using the Darcy–Weisbach equation closely follows a discharge-power form function. The two empirical parameters of the power function depend on the specific pipe characteristics as well as the specific range of discharge values along the lateral. The proposed analytical solution is extended to incorporate the local head loss, the velocity head variation, and the outflow non uniformity along sprinkler and trickle irrigation laterals.

(t) Juana et al. (2005) developed analytical expressions relating water distribution indices in trapezoidal drip irrigation units to design variables which define these units: lengths and diameters of pipes, emitter and lateral spacing, slopes, emitter flow equation parameters, and equivalent lengths characterizing local losses. The proposed expressions are founded in classical hydraulics. They are more accurate than predictions in irrigation practice and are easier to handle than the simulation models frequently proposed to irrigation technicians.

Unit design and irrigation decision making and evaluation can thus be furthered. First, lateral and submain diameters are determined for different shapes of irrigation units to achieve a given water application uniformity. The irrigation time to supply the desired irrigation depth is then calculated. Results are finally compared with values obtained by simulations that take into account hydraulic and manufacture variations in the unit.

(u) The lateral lines of a drip irrigation system consist of pressurized pipelines with inline or online emitters. Proper hydraulic design of drip laterals usually requires the accurate evaluation of the total head losses, represented by friction losses along the pipe and the emitters, and local losses due to the emitter connections. This work extends the local loss evaluation procedure, previously obtained for co extruded laterals, on the basis of new experiments. In addition, a simplified procedure was proposed based on the constant outlet discharge assumption for a quick evaluation of total head losses in drip irrigation lines, taking into account the total local loss due to the emitter connections. The proposed methodology could serve for a quick, approximate evaluation of the total head losses along the laterals.

An experimental investigation was carried out by Provenzano et al. (2005) with five different models of uncoaxial emitters, installed along co extruded polyethylene pipes. The experiments indicated that for the new tested laterals the local loss coefficient was generally higher than previously obtained. This is probably due to the morphology of the emitter connection, which was not taken into account in the predictive equation. Further investigation is however required of the effect of the connection morphology on the values.

A simplified procedure to evaluate the friction and the minor loss for drip irrigation lateral design was then proposed, under the hypothesis to consider the outlet discharge along the lateral constant. The procedure can obviously be considered exact when compensating emitters are used, under the assumption that pressure head variation is limited in the specific range defined by manufacturers. Experiments carried out with 15 different models of co extruded laterals that were commercially available allowed verification of the proposed methodology through comparison between measured and estimated friction and local losses along the laterals. For the examined cases and under the assumptions introduced, the proposed methodology allowed the approximate evaluation of the total head loss along the lateral and consequently the estimation of the pressure head at the upstream end of the laterals with errors always less than ± 2.4%.

(v) Chinea and Dominguez (2006) described the derivation of the total direct and relative reduction factors for both discrete and continuous outflow along mixed service sections of close end multiple outlets pipes. Discrete outflow factors depend on the numbers of outlets along the section and the entire pipeline, while for continuous distribution there is no such dependence. Solutions for close end pipes are also derived. The total relative factors are related to those previously calculated total factors for close end pipes. The concept of "effectiveness" is presented here for close and open end pipes by taking into account the friction loss occurred downstream of the first outlet, resulting in both head and flow variation between that upstream outlet and the remaining outlets along the line. The dependence upon the extremity spacing is also considered.

There are also proposed formulations for mixed factors for intermediate sections between two locations along a close end pipe. A theoretical method has been presented to derive several different direct and relative reduction factors, which represent a wide range of situations in professional design practice for discrete and continuous outflow along the mixed service sections of upstream or intermediate longitudinal portions of multiple outlets close end pipes.

(w) Yildirim (2006) presented an analytical procedure for hydraulic analysis and solving the direct design problem of a single multiple outlets pipe line. The proposed equations, taking into consideration the influence of local energy loss, can be applied for various types of outlets, different flow regimes, and different uniform line slope ranges. In the procedure, for any desired uniformity level and given design slope range with remaining known parameters, the pipe diameter and the pipe length can then be directly designed. For any desired uniformity level, the procedure also provides an opportunity to evaluate the influence of local energy loss, as well as the influence of different uniform line slopes on the pipe geometric characteristics (pipe size and length), and on the corresponding hydraulic variables (operating inlet pressure head, downstream end pressure head, and total energy loss). The present technique can be applied to laterals and manifolds in both sprinkle and trickle systems practically under any situation in this way showing its great flexibility.

(x) Yildirim (2007) developed an analytical procedure to design multiple outlet pipelines taking into account the non uniform outflow profile analysis. Energy relations are improved based on the average friction drop approach with a simple exponential function, to express the non uniform outflow concept. To determine friction head losses, the Darcy-Weisbach formula is used; and the kinetic head change is considered whereas minor head losses are neglected. Several mathematical relationships are also derived for computing extreme pressure heads and their locations of occurrence along the pipeline. The presented method also provides specific lengths of the segments in which the different flow regimes occur along its length. This method simulates pressure and outflow profiles along trickle and sprinkler irrigation laterals and manifolds, as well as gated pipes.

The presented technique was applied to several computational examples to clarify its precision for trickle and sprinkler lateral design and the analytical results were compared with those obtained using the numerical step-by-step method. The comparison test for the various design combinations indicated that, the proposed method is found to be sufficiently accurate in all design cases for both trickle and sprinkler lateral design. The analytical development is simple, direct, and easily adaptable to solve hydraulic design problems of various types of single-diameter multiple-outlet pipelines in different flow regimes and uniform line slope cases. It is preferred to the numerical techniques, which need large amounts of execution time and complex computer operations.

(y) Gyasi-Agyei (2007) established a methodology for estimating drip lateral effective parameter values under field conditions. Grass cultivation on railway embankment steep slopes for erosion control in Central Queensland, Australia, is aided by drip lateral irrigation systems. The effective field values of the lateral parameters may be different from the manufacturer supplied ones due to manufacturing variations of the emitters, environmental factors, and water quality. The hydraulic model takes into account the velocity head change and a proper selection of the friction coefficient formula based on the Reynolds number. Fittings and emitter insertion head losses were incorporated into the hydraulic model. Pressure measurements at some locations within the irrigation system, and the inlet discharges, were used to calibrate the lateral parameters in a statistical framework that allows estimation of parameter uncertainties using the Metropolis algorithm. It is observed that the manufacturer's supplied parameters were significantly different from the calibrated ones, underestimating pressures within the irrigation system for a given inlet discharge, stressing the need for field testing. The parameter posterior distributions were found to be unimodal and nearly normally distributed. The emitter head loss coefficient distribution being very significant suggests the need to incorporate it into the hydraulic modeling.

(z) The design of trickle irrigation systems is crucial to optimize profitability and to warrant high values for the emission uniformity coefficient (EU). EU depends on variation of the pressure head due to head losses along the lines and elevation changes, as well as the water temperature, and other parameters related to the emitters, manufacturer's coefficient of variation, number of emitters per plants and emitter spacing. Trickle irrigation plants are usually designed using small diameter plastic pipes polyethylene or polyvinyl chloride. The design problem, therefore, needs to consider head losses along the lines as well as emitter discharge variations due to the manufacturer's variability. Variations in the hydraulic head are a consequence of both friction losses along the pipe and local losses due to the emitters' connections, whose importance has been recently emphasized. Since each local loss depends on the emitter type in-line or on-line as well as on its shape and dimensions, the morphological variability of the commercially available emitter requires experimental investigations to determine local losses in drip laterals. On the other hand, local losses can be estimated by the mean of computational fluid dynamics (CFD) models, allowing analysis of velocity profiles and the turbulence caused by the emitters' connections. FLUENT software can be considered a powerful tool to evaluate friction and local losses in drip irrigation laterals, after the necessary validation has been carried out by means of experimental data.

Provenzano et al. (2007) carried out the study to assess a Computational Fluid Dynamics (CFD) technique to evaluate friction and local losses in laterals with in-line coextruded emitters. The model was initially used to choose the turbulence model allowing the most accurate estimation of friction losses in small diameter polyethylene pipes, characterized by low Reynolds number. The possibility of using CFD to predict local losses in drip irrigation laterals with a commercially available coextruded emitter was investigated. Simulated local losses were obtained as difference of the total and friction losses along a trunk of pipe, where one single emitter was installed, not considering the emitter outflow. The proposed procedure allows to evaluate local losses for other different emitter models, avoiding tedious and time-consuming experiments.

2.2.3 Manifold

(a) When an area to be irrigated has a high slope gradient in the manifold line direction, an option is to use a tapered pipeline to economize on pipe costs and to keep pressure head variations within desired limits. Saad and Marino (2002) developed a linear optimization model to design a micro irrigation system with tapered, downhill manifold lines, minimizing the equivalent annual cost of the hydraulic network and the annual pumping cost, and maximizing the emission uniformity previously established to the subunit. The input data are irrigation system layout, cost of all hydraulic network components, and electricity price. The output data are equivalent annual cost, pipeline diameter in each line of the system, pressure head in each node, and total operating pressure head. To illustrate its capability, the model is applied in a citrus orchard in Sa˜o Paulo State, Brazil, considering slopes of 3, 6, and 9%. The model proved to be efficient in the design of the irrigation system in terms of the emission uniformity desired.

The linear optimization model developed herein is an effective tool for designing micro irrigation systems with tapered, downhill manifold lines, ensuring the minimization of the equivalent annual cost of the micro irrigation system as well as the maximization of the emission uniformity. For the same annual cost, a tapered pipeline increased the emission uniformity by 4.0, 3.5, and 6.9% for field slopes of 3, 6, and 9%, respectively, when compared with a single diameter manifold line.

(b) The optimum hydraulic design problem for micro irrigation submain units of specified dimensions is solved analytically. New algebraic equations were derived by Valiantzas (2003b) to calculate explicitly the optimum values of the design variables. The design variables are the lengths of two given pipe sizes for the laterals as well as the appropriate lengths of the available pipe sizes for the manifold. Tapered laterals and manifold are selected in such a way that the sum of the costs of the laterals and the manifold is minimized, while the hydraulic design criterion is ensured.

2.2.4 Main / submain

(a) Su et al. (2002) used a Pressure Reducing Pipe (PRP) at the inlet of a lateral in micro irrigation systems to improve water application uniformity. It is composed of an internal spiral and a sleeve pipe and is made of molded polyethylene plastic. It functions to dissipate a pressure head that exceeds the required pressure head of a lateral inlet by directing water flow through the spiral grooved path and creating a certain head loss. An improved design method for submain units using the pressure reducing pipes is based on the hydraulics of the submain unit and the characteristics of the head loss in the PRP. The effects of the PRP on water application uniformity in a submain unit are analyzed by computer simulation. The submain unit with the PRP has higher uniformity than that of the commonly used method. After choosing the PRP, the permissible range of pressure variation in a submain will not need to be considered for the submain length in a layout.

It changes the non uniform distribution of pressure along the submain into a more uniform distribution at the inlets of all laterals in a submain unit, and thereby improves the water application uniformity. Computer simulations showed how the PRP decreases the pressure variation in submain unit. Therefore, it is unnecessary to limit the pressure variation of the submain; but the variation of pressure in the lateral is limited. When some basic parameters for designing a submain unit (including the length and diameter of the submain and lateral, the design emitter discharge, and the required minimum operating pressure head on the emitter) are given. The design procedure includes calculation of the head losses in the submain and lateral, determination of the required operating pressure head at the inlet of the submain and its distribution along the submain and decides on the straight lengths of the threaded shaft using the excess pressure head of each inlet of the lateral.

Using this method, the water application uniformity is determined only by the pressure variation within the lateral and the number of PRPs. The pressure variation along the submain does not directly control the uniformity. Therefore, the layout of the submain line can be more flexible and the length can be longer. Although reduction in pressure variation can be achieved by increasing the size or decreasing the length of the submain, the method described here provides another alternative.

(b) Valiantzas (2003a) derived a new particularly simple equation to solve explicitly the economic design problem of submain lines (micro irrigation manifold and sprinkle irrigation submains) with pumping. The appropriate lengths of the submain line segments with different diameters are directly calculated from the proposed equation in such a way the total cost of energy and pipes is minimized. It is shown that the portion of energy cost affected by changes in the submain pipe sizes is proportional to the inlet pressure head of the submain. A new equation is derived relating the inlet pressure head of a tapered multioutlet pipeline to the average pressure head value. Direct design solutions were obtained for two different cases ensuring two different hydraulic conditions. In the first case, the average value of outflow over all the outlets (emitters) of the system is imposed to be identical to the required average outlet discharge. This implies that the average pressure head value in the submain is imposed to be equal to an a priori known constant. In the second case the energy cost is assumed proportional to the friction losses along the submain.

2.2.5 Low cost technology

(a) The drip irrigation system has emerged as appropriate water saving and production augmenting technique for wide spaced crops and also for commercial crops. However, the initial cost of the drip set is higher and use of the system is limited.

Hiwase et al. (2004) modified the system to semi-portable mode keeping water source and pumping plant fixed with extended main line. The drip irrigation system originally designed for 2.5-hectare area whose annual cost of operation was Rs. 44,577 was made semi-portable. It was used at Khairkhed village for irrigating 13 ha pre monsoon Cotton and 12 ha Pigeon pea during the year 2001-2002 and 2002-2003 and benefited the farmer by Rs. 21,500 and Rs.11,775 per hectare per year over rain fed respectively. The yield obtained was three times more than rain fed in both crops. The net benefit earned was Rs.4,20,800 in one season from 25 hectare land due to supplementary irrigation provided through semi-portable drip irrigation system where shifting of system from one block to other requires just 2 man days. Study revealed that, the semi-portable drip irrigation system of particular capacity could be used for large area of the same crop in different time. The set can be used even for life saving irrigation of different crops. Hence the use of semi-portable drip irrigation system is strongly advocated to the farmers. Because of having semi-portable advantage of the system studied in this investigation, the system cost has been reduced to one tenth. Also, if this system is shifted in day time and allowed to run in the whole night, whenever power will be available it can supply water to a crop for it's life saving. Thus, this will be a solution to the main constraints like high cost of installation and uncertainty of power experienced in popularization of a drip an efficient system of irrigation.

(b) Drip irrigation is a technique by which water and fertilizers can be placed directly near the root zone of the plants. High initial cost compared with other irrigation methods is the major drawback of the drip irrigation systems. Although, government subsidizes these systems up to 50 %, yet their high initial cost and necessity of pump and other accessories, make them a distant dream for the poorest of tribal farmers. In this situation a low cost low head drip irrigation system may prove to be a boon for them.

Singh et al. (2004) compared the economic viability of the two irrigation systems (i.e. Low cost low head type and Conventional type) at farmers' fields for Okra. Benefit cost ratio was found to be 3.8 and 2.6 with and without subsidy respectively for the Low cost low head drip irrigation system, whereas for the Conventional drip irrigation system the benefit cost ratio was found to be 2.45 and 1.73 with and without subsidy respectively. So it may be concluded that for the area as small as about one tenth of a hectare, the low cost low head drip irrigation system is more economical than the conventional one. Access to irrigation water is a critical element in meeting the food demands of a rapidly increasing population in the middle mountains of Nepal. The recent introduction of low-cost drip irrigation (LCDI) to Nepal represents an affordable means of expanding irrigation into rain fed areas, there by increasing land productivity.

(c) Westarp et al.(2004) presents a comparison of the effects on soil volumetric water content and cauliflower yield of three irrigation methods Low Cost Drip Irrigation (LCDI), Conventional Drip Irrigation (CDI) and hand watering) operated under three different irrigation regimes in the Jhikhu Khola Watershed, Nepal. Irrigation regime one supplied only half of the estimated crop water requirement, characterized by small volumes applied on alternate days. The other two irrigation regimes (regimes two and three), supplied the full estimated crop water requirement, however differed in application timing. Small volumes were applied frequently (daily) under regime two, whereas in regime three, greater water volumes were applied les frequently (alternate days for the majority of experiment). Although differences in the Soil Volumetric Water Content (SVWC) were present between the irrigation methods, differences were not consistent between three irrigation regimes. Regardless of irrigation regime, cumulative cauliflower yields were lowest under conventional drip irrigation. In contrast, there were significant differences in cauliflower yield between LCDI and hand watering between irrigation regimes. Irrigation regime one resulted in lower SVWC and lower cumulative yields than regimes two and three however. Water –use efficiency was greater under regime one than under regime two and three. These results suggest that LCDI and hand watering are both viable options to increase food production in water scarce, small-scale farming in Nepal, however, long-term economic and labour benefits are greater under LCDI.

(d) Visalakshi et al. (2005) carried out the research works at the Agronomic Research Station, Chalakudy, Kerala Agricultural University for the development of an affordable, dependable, simple and farmer friendly technology, resulted in a low cost micro sprinkler head. The rotating sprinkler head is made of a small piece of 12mm/8mm diameter good quality LDPE pipe, plugged at both ends. It is provided with 1mm diameter nozzles 5mm away from both ends on opposite sides. A 6mm diameter micro tube is attached to the sprinkler head unit at the center through the pin connector. The other end of the micro tube can then be attached to the lateral, through another pin connector. The micro tube with the sprinkler head unit is tied to a riser pipe, fixed near the plant to be irrigated. The moment of couple constituted by the stream coming out of the nozzles causes the emitter to rotate while in operation. The performance of these sprinkler heads were evaluated by observing the effective wetting area, discharge rates, water distribution pattern, variation of effective wetting area with different pressures and heights of riser pipe etc. The micro sprinklers discharge 35 – 40 lph, wetting an area of 2 – 2.5 m diameter, under 1 – 2 kg/cm^2 pressure. For close growing crops, the investment cost is Rs. 10,000 less, than that required for drip irrigation system. Lesser clogging susceptibility, more distribution uniformity, reduced investment cost etc. are the special advantages of the system.

2.2.6 Case studies

(a) Micro Drip Irrigation System (MDIS) is now being identified as an additional income generating technology while looking at the evolution of the market driven approach to reaching small farmers. An attempt was made by Rao and Sahu (2004) to design, develop and evaluate it for growing vegetables in the farmer's field (Village Nardha, District Durg). The manifold and its laterals were designed and operated as single unified system controlled by a single valve. A water tank placed at variable height was used to develop pressure head. A flexible 16 mm diameter pipe distributed water between the laterals of 12 mm diameter. Micro tubes of 1.2 mm diameter were used as emitters. FAO's CROPWAT model was used to estimate the evapotranspiration (ET) of various vegetable crops. Irrigation was scheduled using ET values and soil characteristic data. To achieve a more realistic design, the interrelationship between Reynolds number and friction factor was incorporated by considering the effect of varying velocities of flow through various pipe sections. System's hydraulic performance was evaluated by measuring discharge variation among the different emitters, estimating friction head losses in different components.

The correlation was developed between average discharge of emitters and pressure head. The Coefficient of Uniformity (CU) and Emission Uniformity Coefficient (EU) were also estimated. The CU was found to be excellent (>95%) and EU was also found to be reasonably good (>90%). The economics of MDIS was worked out. The system cost was Rs. 78,000 ha^{-1}. On an average the use of low cost MDIS produced 25-35% higher crop yield and saved 45-48% water, 45% labour cost and 50% of fertilizer cost. The benefit cost ratio was higher in case of MDIS (5.34) as compared to basin irrigation (4.14). Thus in one season (1/3rd year) additional cost on MDIS can easily be recovered.

(b) Zade et al. (2004) conducted experiment on four locations of western Vidarbha namely Akola, Amravati, Yeotmal and Buldhana for groundnut (summer). Weekly rainfall data of last twenty five years (1970 to 1995) was analyzed for each location and rainfall curves were drawn at 50%, 70% and 80% probability levels. The values of weekly reference evapotranspiration (ETo) were calculated by using weather data on relative humidity, temperature, wind speed and cloudiness. Crop coefficient curves were developed and using these values and ETo values at 70% probability level, crop consumptive use of water was predicted. The consumptive use of water for Akola, Amravati, Yeotmal and Buldhana obtained are 777.29, 819.47, 751.19 and 732.67 mm respectively.

(c) Dripper is a critical component of drip irrigation system. The design of dripper considers the proper material construction (elastomer), its manufacturing process and the hydraulics performance. In order to test the hydraulic performance of market available drippers, 19 different types of dripper samples from 6 different makes were procured and tested in the computerized laboratory (Supervisory Control and Data Acquisition) at C.I.A.E., Bhopal. Most of the testing systems use conventional instruments for measuring pressure and discharge with manual controls, which are likely to result in human error in the data recording. Therefore a PLC based automated dripper testing setup was used in this study.

Out of 19 different types of drippers, 4 were pressure-compensating (PC) type and 15 were non-pressure compensating (NPC) type. These dripper samples were of 3 different rated discharge viz. 2, 4 and 8 lph. Out of above 19 dripper selected, 4 were of 2 lph, 7 were of 4 lph and remaining 8 were of 8 lph rated discharge. 25 dripper samples, each of 19 above different types and makes were tested for pressure and discharge relation. 100 dripper samples, each of 19 above different types and makes were tested for studying the coefficient of manufacturing variation. 6 dripper samples were tested for barb loss with three replications in different dia. of lateral pipe (12mm and 16mm). Test results of these drippers were compared with BIS and ASAE standards and then rated as excellent, good, average and unacceptable range of performance. Testing was initiated by selecting 6 operating pressures from 50 to 300 kPa with an increment of 50 kPa as per BIS (IS: 13487, 1992). The hydraulic parameters estimated were flow exponent and discharge co efficient from discharge – pressure relationship, coefficient of manufacturing variation, the uniformity coefficient, barb loss of drippers and protrusion area and head loss relation.

Kishor et al. (2005) developed the pressure and discharge relations for all drippers by fitting power equation to the data. The drippers were classified based in the CVm values obtained at 100 kPa with 100 sample size. The discharge deviations in the case of PC drippers were observed below 5% resulting in high uniformity coefficient of more than 95%. All the four PC drippers and three NPC drippers were classified as "Class A" drippers as per BIS code. Four NPC drippers had the CVm less than 5% indicating the good performance, while 6 NPC drippers had CVm in the range 5-10% indicating the average performance while the remaining 5 NPC drippers had CVm more than 10% indicated the unacceptable range of performance. Two of the NCP dripper viz PANC2 and PRNC1 were found unacceptable as their CVm was more than 15% as per ASAE code. The BIS has no classification beyond 10% variation in the discharge. The uniformity coefficient of PC dripper was found to be equal or more than 95% at all operating pressure of 50 to 300 kPa. The drippers of NC2 and NC3 had maximum uniformity with 98% indicating the excellent performance. Among NPC drippers, four were found to have uniformity coefficient in the range of 94 to 98%, 7 had uniformity coefficient in the range of 90 to 95%. The four drippers sample were found in the unacceptable range of uniformity coefficient in the range of (79-86%). The average head loss due to barb connection in lateral was found to be 0.065 and 0.058 m for 12 and 16 mm lateral size respectively with an average protrusion area of 20.73 mm^2 of selected drippers.

(d) Precision irrigation is a highly important ingredient in precision farming. Precision farming is incomplete without this component. Soil moisture status at different stages of crops plays a major role in physiological development of each plant. A pressure compensated automatic micro sprinkler system was procured and was installed by Kishore et al. (2005) for 0.3 ha area at CIAE, Bhopal.

The system was evaluated for precision in distribution as well as its automatic control on soil moisture basis. The precision irrigation system designed consists of 75 mm main and 63 mm submains, which are water sourced by a ground water pump. The mains & submains both are kept above laterals and covered with soil for protection from weather. The irrigation was provided by pressure compensated micro sprinklers or micro jets for uniformity of distribution, with 50% diametrical overlapping. The test set up was installed for observing distribution and coefficient of uniformity. The distribution uniformity and coefficient of uniformity was found 97.35% and 98.33% respectively.

2.2.7 Crops

(a) Bhuyar et al. (2003) conducted the field experiments on summer groundnut (Arachis hypogaea L.) cv. TAG-24 to study the response of summer groundnut to different irrigation methods during three years viz., 1999-2000, 2000-2001 and 2001-2002. The experiment was laid in randomized block design with five replications and four treatments as drip, micro sprinkler, drip inline and broad bed furrow (BBF) irrigation on clay loam soil. The irrigation for drip, micro sprinkler and drip inline was scheduled daily equal to previous day crop evapotranspiration and for BBF treatment irrigation was scheduled at 40 mm crop evapotranspiration with Irrigation water to crop evapotranspiration ratio equal to 0.75. During 2001-2002, the net irrigation requirement was 64.09 ha-cm in micro irrigation systems and 84.78 ha-cm in broad bed furrow system, respectively. The water saving in micro irrigation treatments over BBF was 24.40 per cent. It was observed that irrigation water use efficiency was highest in micro sprinkler irrigation system (0.63 q/ha-cm) followed by drip inline (0.61 q/ha-cm) and drip (0.59 q/ha-cm). The lowest irrigation water use efficiency was found in BBF irrigation treatment (0.32 q/ha-cm). The highest dry pod yield and haulm yield were found in micro sprinkler treatment in the tune of 40.14 q/ha and 54.30 q/ha, respectively, followed by drip inline, drip and broad bed furrow, during 2001-2002. Pooled analysis of three years shows the highest dry pod yield in micro sprinkler (44.18 q/ha) followed by drip inline (41.65 q/ha), drip (39.78 q/ha) and BBF (27.08 q/ha).