CELSOC

CONSULTING ENGINEERS AND LAND SURVEYORS OF CALIFORNIA

Presents:

The 2004 Drainage Law Seminar

Course Syllabus

CELSOC 2004 DRAINAGE LAW SEMINAR AGENDA

- **9:00 a.m.**
  - **Program Introduction**
  - **Introduction to The Law**
- **10:30 a.m.** **Break**
- **10:45 a.m.**
  - **Basic Drainage Law**
    - **Legal Theories**
    - **Drainage Law Rules**
    - **Flood Control Projects/Inverse Condemnation**
- **12:15 p.m.** **Lunch**
- **1:30 p.m.**
  - **Standard of Practice Design Issues**
- **3:30 p.m.**
  - **Forearming for Litigation**
- **4:00 p.m.** **Adjournment**

Presenters

Michael J. Murtaugh
Attorney, Founding Partner
Murtaugh Meyer Nelson & Treglia LLP

Mr. Murtaugh is a lawyer with personal practice emphasis in the areas of construction and professional liability, and with more than 25 years of experience working with design professionals. A 1973 graduate of UCLA School of Law, Mr. Murtaugh has also lectured on construction law, design professional risk management and professional service contracts.

Theordore V. Hromadka II, Ph.D., Ph.D., Ph.D., P.E., P.H.
Professor, School of Natural Science and Mathematics, California State University, Fullerton

Dr. Hromakda is a registered civil engineer and a certified professional hydrologist who holds three Ph.D.'s in engineering and related subjects. A principal at Hromadka & Associates, he has authored 350 journal papers – as well as 21 books – about hydrology. Additionally, he has received numerous research appointments and has prepared 55 master plans of drainage and environmental systems.

TABLE OF CONTENTS

I. DRAINAGE LAW

A. The Law in General.

1. The Law Defined.

The law, for the purpose of coming to grips with its requirements, can well be defined as the complex confusion of often contradictory, sometimes unsettled, and always ever-changing rules of conduct which are enforced by the civil authorities.

As this definition underscores, working with the law requires a flair for ambiguity and argument, a tolerance for uncertainty, and a distrust of simple answers (to paraphrase the John Maynard Keynes observation about economics: every simple statement about the law is wrong, except this one). Certainty and predictability is an elusive goal of the law; but in any particular situation, the applicability of a legal rule is arguable. Opposing parties can always assert that different rules ought to be applied according to their interpretation of the situation, or of the rule itself; and it can always be argued that a clearly applicable rule ought to be changed. The sad awful truth, as known to any experienced legal practitioner, is that ultimately the law of any particular case is what the judge says it is.

2. The Sources of the Law.

The law, which is to say the body of governmentally enforced rules, is derived from four related but distinct well-recognized types of sources:

- The federal and state constitutions, which prescribe the fundamentals of how the government is to work (e.g., the role of the courts or the existence of a civil service system), and also certain fundamental individual rights (e.g., the right to trial by jury, the right to privacy, and the right to just compensation for a governmental taking through inverse condemnation). As with all aspects of the law, some constitutional rules are based on straightforward declarations (e.g., the existence of a civil service or the right to trial by jury), while others have been derived over time by argument (e.g., the rights of privacy and inverse condemnation).

- Legislative enactments are generally referred to as statutes at the federal and state levels, and as ordinances at the county and city levels; but by whatever name, they are the particular rules generated by the legislative process which attempt to regulate directly or indirectly virtually every aspect of our societal dealings. Political in origin (a standard cliché: those who like sausage and law should never watch either being made), often poorly drafted, and almost never coordinated one with another, and numbering in the millions, these enactments provide both an endless source of argument about what rules are applicable to what situations, and the basis for incomprehensibly voluminous bureaucratic regulations discussed below.

- Bureaucratic regulations (and, to a much lesser extent, executive orders) are rules promulgated usually by unelected government officials generally to flesh out the details of statutory schemes (although as a practical matter these regulations can effectively create whole new laws such as, for example, the law of sexual harassment which now permeates every business in the nation, but which originated in 1980 federal EEOC regulations).

- Case law, sometimes referred to as common law, are those appellate court decisions which are published so as to have precedential effect (pursuant to the legal doctrine of *stare decisis*) concerning the justices' interpretation of constitutional, statutory and regulatory rules, as well as those rules based on earlier appellate court decisions. As with statutes and regulations, reported appellate decisions are numerous beyond comprehension and affect virtually every aspect of the law; but unlike statutes and regulations, appellate court decisions are the result of pure legal reasoning untainted by politics, at least in theory. Few areas of the law are based as much in case law as is drainage law, with the California Supreme Court having noted that these common law rules are "complex and unique" and "one of the most confusing areas" in which courts deal.

Because those rules which are governmentally enforced are based upon the well-recognized types of sources discussed above, it follows that some common notions as to the basis of the law are incorrect. For example:

- The commencement of a lawsuit says nothing about the law. Anyone can start a lawsuit by filing a complaint with any Superior Court saying absolutely anything, and the only judicial vetting of a complaint at the time of filing concerns the calculation of the Court's filing fee.

- Jury verdicts are not the law, but rather merely a factual finding based solely on whatever particular evidence was presented in a particular case. For example, a jury's finding that a particular engineer met or failed to meet the applicable standard of practice in a particular case has absolutely no legal precedential value, and is very unlikely to have any impact on the legal rules which will be applied in subsequent cases.

- The ruling of a trial court judge in a particular case, while of overriding importance in that case, and while perhaps offering some indication of how that or other judges might rule in similar future cases, technically lacks precedential value, and is only as persuasive as some lawyer can convince some judge that it ought to be.

- Formal attorney general opinions, while perhaps insightful and persuasive, do not constitute legal precedence, and have at best an indirect influence on the determination of the law applicable to any particular case.

- Industry standards or practices are not the law as such, although evidence of them might be persuasive in determining, for example, whether an engineer met the applicable standard of practice in a particular case, or how an ambiguous contract scope ought to be interpreted.

3. <u>The Implementation of the Law</u>.

Governmental enforcement of the rules which constitute the law is accomplished most dramatically by a criminal prosecution, but fortunately the rules concerning drainage law are typically implemented by relatively undramatic civil lawsuits or bureaucratic entitlements.

a. <u>Civil lawsuits</u>.

A civil lawsuit is a legal proceeding, or series of proceedings, in which a legal entity such as an individual or corporation ("the plaintiff"), seeks to enforce certain claimed rights against another party ("the defendant") by obtaining, pursuant to one or more legal theories (i.e., predetermined requirements for what facts must be alleged), an enforceable court order ("a judgment") directing the defendant to pay money to the plaintiff ("damages"), and/or occasionally to do or to refrain from doing some act ("an injunction") or to obtain a declaration of rights ("a declaratory judgment"). Invariably, obtaining such an order requires some sort of evidentiary hearing, usually a full-blown trial involving the presentation of formal evidence; and once obtained, the order is subject to judicial review by an appellate court. Examples of typical drainage law lawsuits include:

- A plaintiff landowner sues a defendant adjacent landowner seeking to enjoin the present drainage flow and damages for past flooding; or a plaintiff downstream riparian owner sues a defendant upstream developer for damages caused by changes in the watercourse resulting from upstream development.

- A plaintiff landowner sues a defendant county seeking inverse condemnation damages as a result of the inadvertent drainage consequences of a public works project.

- Flood victims (or their subrogated flood insurers) sue a county flood control district seeking tens of millions of dollars in damages because of the failure of a flood control project to have prevented the flooding of the plaintiffs' homes.

b. **Bureaucratic entitlement.**

Bureaucratic entitlements, typically permits or approvals, bestow upon a party a legal right (perhaps subject to challenge by lawsuit) to do certain things as the result of decisions rendered by government officials with statutory or regulatory jurisdiction over the subject matter of the action in question. For example:

- Tentative tract map approval
- Grading permit issuance

B. **General Legal Theories Commonly Invoked in Drainage Litigation.**

As mentioned above, the legal heart of a civil lawsuit is the plaintiff's legal theory or theories, a legal theory being a set of operative facts which the plaintiff must prove in order to obtain the desired judgment; and the legal theories commonly invoked in drainage litigation are briefly discussed or outlined below.

1. **Legal Theories Applicable to Engineers.**

a. **Professional negligence (and negligence per se).**

- Elements [see Appendix 1, the basic California jury instructions for a professional negligence action]:
  - Duty to comply with the applicable standard of practice or care (i.e., to have that degree of learning and skill, and to use the care and skill ordinarily exercised by reputable engineers practicing in the same or similar locality and under similar circumstances, as well as to use reasonable diligence and his or her best judgment in the exercise of that skill and the application of that learning).
    - Determined by a lay jury based upon the dueling testimony of forensic experts.
    - Negligence per se: A statute, ordinance or regulation (e.g., an ordinance regarding drainage design) can establish a professional duty on the part of a professional engineer, the violation of which may well constitute negligence.
  - Breach.

- Causation (i.e., a substantial contributing factor to costs or losses that otherwise would not have been incurred).

- Affirmative Defenses.
  - Comparative Fault.
  - Assumption of the Risk.

b. <u>Breach of contract</u>.

In addition to an express or implied obligation to perform professional services consistent with the applicable standard of practice (i.e., to fulfill the professional duty discussed above), a professional services contract can further obligate an engineer to obtain certain results (e.g., that certain schedule and budget constraints will be met, or a particular project will perform to certain standards); and while the law of contracts is too complex to go into here, in general the courts will enforce such obligations.

c. <u>Strict liability</u>.

Under current and well-settled California law, a provider of professional services is not subject to any strict liability theories such as products liability or implied warranty, the leading judicial pronouncement being: "Those who hire [professionals] are not justified in expecting infallibility, but can expect only reasonable care and competence. They purchase service, not insurance." *Gagne v. Bertran* (1954) 43 Cal.2d. 481, 489.

2. <u>Legal Theories Applicable to Landowners, Both Private And Governmental (Tort Claims Act of 1963)</u>.

a. <u>Trespass</u>.

- Defined: Trespass is an unlawful interference with the possession of property; the essence of trespass is an unauthorized entry onto the land of another.
- Elements:
  - Plaintiff's possession of the property.
  - Defendant's volitional act or failure to act.
  - Unlawful interference with possession by intrusion by person or things (*e.g.*, draining water onto).
  - Causation.

- Affirmative Defenses

  - Privilege (*e.g.*, drainage law rules).

  - Consent, express or implied.

  - Necessity: one is privileged to enter and remain on the land in possession of another if it reasonably appears to be necessary to prevent serious harm to the land or chattels of the other party.

  - Entry under color of authority: entry of a law enforcement officer on the land of another and the lawful discharge of his or her duties is not considered a trespass.

  - Entry to abate nuisance: if a private nuisance results from a mere omission of the wrongdoer, and cannot be abated without entering on the land, but reasonable notice must be given to the wrongdoer before entering to abate it.

  - If defendant's act was negligent, then comparative fault and assumption of the risk.

b. <u>Nuisance</u>.

- Defined: Anything that is injurious to health, is indecent or offensive to the senses, or is an obstruction to the free use of property, so as to interfere with the comfortable enjoyment of life or property or that unlawfully obstructs the free passage or use, in the customary manner, of any navigable lake, river, bay, stream, canal, or basin, or any public park, square, street or highway. *Civil Code §3479. See generally Civil Code §§3479-3503; Code of Civil Procedure §§731, 731.5; Penal Code §§370-372.*

  - Public Nuisance: A public nuisance is "one which affects at the same time an entire community or neighborhood, or any considerable number of persons, although the extent of the annoyance or damage inflicted upon individuals may be unequal." *Civil Code §3480.* In addition, a private party can maintain an action based on public nuisance "if it is specially injurious to himself, but not otherwise." *Civil Code §3493.*

- Private Nuisance: Unlike public nuisance, which is an interference with the rights of the community at large, private nuisance is a civil wrong based on disturbance of rights in land. *Venuto v. Owens-Corning Fiberglas Corp.* (1971) 22 Cal.App.3d 116, 124.

- Note: A nuisance may be both public and private, but to proceed on a private nuisance theory the plaintiff must prove an injury specifically referable to the use and enjoyment of his or her land.

- Elements: The particular condition or particular conduct interferes with the use of land or the exercise of public rights.

  - The act may be done negligently, intentionally, or involve ultra-hazardous activity.

  - The interference is substantial and unreasonable, and such that would be offensive or inconvenient to the normal person.

  - The claimed damages must be proximately caused by the defendant's nuisance.

  - To establish a private nuisance, that the condition or conduct interfered with the plaintiff's use or enjoyment of his or her property.

  - To establish a public nuisance, that the condition or conduct affected a substantial number of people at the same time.

- Affirmative Defenses:

  - If defendant's act was negligent, then comparative fault and assumption of the risk.

  - A statute expressly authorizes the conduct.

  - The business is operating in a permitted zone.

  - There exists a pre-existing agricultural use.

c. **General negligence.**

- Elements:
  - Duty (*i.e.*, "Everyone is responsible, not only for the result of his or her willful acts, but also for an injury occasioned to another by his or her want of ordinary care or skill in the management of his property or person . . . " *California Civil Code §1714*).
  - Breach.
  - Causation.
- Affirmative Defenses:
  - Comparative Fault.
  - Assumption of the Risk.
  - Privilege.

d. **Strict liability.**

- Mass-produced housing: Developers of mass-produced residential projects are strictly liable for any project "defects," an undefined term often used to establish liability for drainage problems; and while this theory is not directly applicable to professional engineers as such, it provides the basis for the current epidemic in "construction defect" litigation in which engineers often become embroiled. (Note: pursuant to California's new "Right to Repair Act," for homes sold after December 31, 2002, the undefined concept of "defect" is supposedly replaced by numerous statutorily delineated "functionality standards.")
- Impounded Water: The law imposes upon those who engage in "ultra-hazardous activities" strict liability for the consequences of those activities, the leading appellate court decision being the 1868 English case of *Rylands v. Fletcher*, 3 House of Lords 330, in which such liability was imposed upon a landowner for the construction of an ill-fated reservoir. Just what actions courts consider to be "ultra-hazardous," however, changes over time as technology evolves and activities become more or less common; and whether impounding water constitutes an ultra-hazardous activity in California has remained unresolved for 60-plus years.

3. **<u>Legal Theories Applicable to Governmental Entities Only</u>.**

a. **<u>Dangerous condition of public property (*Government Code §§830, et seq.*)</u>.**

- Elements:

  - Real or personal property owned or controlled by the public entity.

  - A condition that creates a substantial risk of injury on the property or on or to adjacent property when such property or adjacent property is used with due care in a reasonably foreseeable manner.

  - A negligent or wrongful act or omission of an employee of the public entity within the scope of his or her employment created the dangerous condition; or the public entity had actual or constructive notice of the dangerous condition in sufficient time prior to the injury to have taken measures to protect against the dangerous condition.

  - Causation of the kind of injury that was foreseeable.

- Affirmative Defenses:

  - Immunity: Public entities may use any defenses that would be available if the public entity were a private person (*Govt. Code §815(b)*).

  - Design Immunity: Pursuant to *Government Code §830.6*, "neither a public entity nor a public employee is liable ... for any injury [from a dangerous condition] caused by the plan or design or the construction of, or an improvement to, public property where [the] plan or design has been approved in advance of the construction or improvement by the legislative body of the public entity or by some other body or employee exercising discretionary authority to give the approval or where the plan or design is prepared in conformity with the standards previously so approved. . . ."

- Reasonableness Defense: A public entity is not liable under *Government Code §835.4(a)* for injury caused by a condition of its property if that entity establishes that the act or omission that created the condition was reasonable.

b. **Inverse condemnation.**

- Source: *Cal.Const., Art. I, §19* [once §14] -- "Private property may be taken or damaged for public use only when just compensation, ascertained by a jury unless waived, has first been paid to, or into court for, the owner." -- as first interpreted by the Supreme Court in the 1965 landmark case of *Albers v. County of L.A.* (1965) 62 Cal.2d 250.

- Effect: Strict liability (i.e., liability without regard to fault) for physical injuries to real property (plus reasonable mitigation costs, interest and attorneys fees, and subject to the plaintiff's duty to mitigate) which are proximately caused (i.e., a substantial cause-and-effect relationship excluding the probability that other factors alone produced the injury) by public works, or governmentally approved quasi public private improvements, as deliberately designed, constructed and maintained (e.g., as opposed to the negligence of a public employee, for which there may well be negligent tort liability instead).

- Exceptions (recognized in *Albers*):

    - The police powers exception set forth in *Gray v. Reclamation Dist. No. 1500* (1917) 174 Cal. 622: Not applicable to the exercise of police powers pursuant to *Cal. Const. Art. XI, §7 (i.e.,* emergency actions necessitated by an imminent and substantial threat to public health or safety); and when private property is directly taken or damaged in an emergency situation by the government due to public necessity and to avert impending peril, the damages are noncompensable. *See Holtz v. Superior Court* (Ca.Sup.Ct. 1970) 3 Cal.3d 296. For these purposes, an "emergency" is an unforeseen situation calling for immediate action; the term comprehends a situation of grave character and serious moment, and is evidenced by an imminent and substantial threat to public health or safety. *Los Osos Valley Associates v. City of San Luis Obispo* (1994), 30 Cal.App. 4th 1670, 1681.

- The flood control improvements exception set forth in *Archer v. City of Los Angeles* (1941) 19 Cal.2d 19: Not applicable in situations where the "complex and unique province of water law" creates a "right to inflict injury" pursuant to the civil law rules regarding natural watercourses and flood waters -- significantly modified by post-*Keys* as discussed below.

4. Environmental Laws.

While even a cursory overview of the relatively new but already extraordinarily complex area of environmental law is beyond the scope of this program, it should be noted that in this day and age most projects must be developed and designed with an eye towards applicable environmental requirements imposed pursuant to an overlapping confusion of state and federal statutory schemes such as the National Environmental Policy Act, the California Environmental Quality Act, the Federal Clean Water Act of 1972, the Federal Water Quality Act of 1987, the EPA's National Pollution Discharge Elimination System Permit Program, the National Flood Insurance Program, the drainage provisions of the California Fish and Game Code, and the California Coastal Act.

C. Basic California Drainage Laws.

1. Traditional "Civil Law" Rules.

While long ago courts developed the "common enemy doctrine" pursuant to which a landowner was supposedly free to discharge drainage without regard to the consequences to the receiving adjacent land or watercourse, for nearly a century before the onset of the modern "rule(s) of reasonable use" discussed below, (i.e., at least since the California Supreme Court's once landmark decision in *Ogburn v. Connor* (1873) 46 Cal. 346, California courts followed traditional civil law rules (which were derived from the Napoleonic Code, which in turn was derived from Roman law) which involve three different classifications of water as follows:

a. Surface waters.

"Surface water" is naturally occurring water (i.e., from precipitation or springs) which is diffused over land and not part of a watercourse, lake or pond.

The civil law applicable to surface waters is generally known as the natural flow rule: a servitude of natural drainage such that the lower estate must accept natural drainage, but the upper estate has no right to alter the natural drainage (as the courts "reasoned," *aqua currit et debet currere ut curree solebat*, or water runs and ought to run as it is accustomed to run).

For example, in *LeBrun v. Richards* (Calif. Sup. Ct. 1930) 210 Cal. 308, an upper landowner plaintiff recovered $1,000 in damages from a lower adjacent landowner

- Reasonable drainage alteration opposed to reasonable mitigation measures results in liability.
- Reasonable drainage alteration opposed to a lack of reasonable mitigation measures avoids liability.

Regarding the fourth logical permutation of reasonableness, unreasonable drainage alteration opposed to unreasonable mitigation measures, while the Supreme Court has yet to rule, pursuant to basic principals of negligence, trespass and nuisance law, and as noted by at least one district court of appeal in *Sheffet v. County of Los Angeles* (1970) 3 Cal.App.3d 720, the probable answer lies in the doctrine of the duty to mitigate damages: "[t]he person who may minimize damage and fails to do so cannot recover for the excess damage occurring."

"Reasonableness" in the context of the *Keys* rules (as opposed to, say, the context of negligence tort liability) is a question of fact to be determined from all the relevant circumstances including an objective analysis of the utility of the conduct and the gravity of the harm, the foreseeability of the harm and the intentions of the landowners. [1] In particular, noting that "[w]hat constitutes reasonable conduct is not always easy to ascertain," the *Keys* court stated:

> "The issue of reasonableness becomes a question of fact to be determined in each case upon a consideration of all the relevant circumstances, including such factors as the amount of harm caused, the foreseeability of the harm which results, the purpose or motive with which the possessor acted, and all other relevant matter. (*Armstrong v. Francis Corp.* (1956) *supra*, 20 N.J. 320.) It is properly a consideration in land development problems whether the utility of the possessor's use of his land outweighs the gravity of the harm which results from his alteration of the flow of surface waters. (*Sheehan v. Flynn* (1894) 59 Minn. 436 [61 N.W. 462, 26 L.R.A. 632].) The gravity of harm is its seriousness from an objective viewpoint, while the utility of conduct is its meritoriousness from the same viewpoint. (Rest., Torts, §826.) If the weight is on the side of him who alters the natural watercourse, then he has acted reasonably and without liability; if the harm to the lower landowner is unreasonably severe, then the economic costs incident to the expulsion of the surface waters must be borne by the upper owner whose development caused the damage."

Also instructive on the issue of "reasonableness" is the district court opinion in *Sheffet v. County of Los Angeles* (1970) 3 Cal.App.3d 720, in which the court responded to the defendants' contention that a plaintiff landowner had not acted reasonably because nothing had been done to protect the plaintiff's property from the consequences of the defendants' drainage alteration stating:

[1] Ref. summary of "reasonableness" factors re: surface waters, Appendix 4.

"Defendants contend that plaintiff acted unreasonably because he failed to take any affirmative action to protect his property and never consulted any person or firm with respect to alternations in his property which might protect it from the flow of surface waters. Defendants would have us read *Keys* as necessarily requiring affirmative action on the part of a lower landowner before he can complain of unreasonable surface water diversion by any upper landowner. However, such an interpretation of *Keys* would in many instances place an unreasonable burden on the lower landowner. All that he is required to do is act reasonably.

* * *

"Reasonable conduct may or may not require affirmative action by the lower owner, depending upon all the circumstances. The social utility of the upper owner's conduct must be weighed against the burden that such conduct would impose on the lower owner. More often than not, the lower owner's unreasonable conduct will consist not of his failure to take affirmative steps to protect his property, but of affirmative conduct increasing the danger to his property."

(ii) <u>Natural watercourses</u>

In *Locklin v. City of LaFayette* (Calif. Sup. Ct. 1994) 7 Cal.4th 327 -- nearly 28 years and several conflicting appellate court decisions after *Keys* -- the California Supreme Court expressly extended the *Keys* "test of reasonableness" modification of the civil law rule regarding surface waters to the civil law rule regarding natural water courses stating that[2]:

". . . we agree with those courts which have held that *Keys v. Romley* states a rule that is applicable to all conduct by landowners in their disposition of surface water runoff whether the waters are discharged onto the land of an adjoining owner or into a natural watercourse, as well as to the conduct of upper and lower riparian owners who construct improvements in the creek itself.

"Although *Keys v. Romley* was decided in the context of damage caused to adjacent land by the discharge of surface waters, the reasoning of the court has broader applicability. The decision rests on the broad principle that a landowner may not act 'arbitrarily and unreasonably in his relations with other landowners and still be immunized from all liability. It is therefore incumbent upon every person to take reasonable care in using his property to avoid injury to [other] property. . . .'

[2] Ref. summary of "reasonableness" factors re: natural water courses, Appendix 5

> (*Keys v. Romley, supra*, 64 Cal.2d at p. 405.) While the court spoke in terms of the responsibilities of adjacent landowners with respect to surface waters, we did not intend thereby to imply that the obligation to take reasonable care was not one imposed also on upper and lower riparian owners. There is no exception from the rule of reasonableness for riparians. No logic would support such a distinction and we decline to recognize one."

In particular, the Court held:

> "When alterations or improvements on upstream property discharge an increased volume of surface water into a natural watercourse, and the increased volume and/or velocity of the stream waters or the method of discharge into the watercourse causes downstream property damage, a public entity, as a property owner, may be liable for that damage. The test is whether, under all the circumstances, the upper landowner's conduct was reasonable. This rule of reasonableness applies to both private and public landowners, but it requires reasonable conduct on the part of downstream owners as well. This test requires consideration of the purpose for which the improvements were undertaken, the amount of surface water runoff added to the streamflow by the defendant's improvements in relation to that from development of other parts of the watershed, and the cost of mitigating measures available to both upper and downstream owners. Those costs must be balanced against the magnitude of the potential for downstream damage. If both plaintiff and defendant have acted reasonably, the natural watercourse rule imposes the burden of stream-caused damage on the downstream property."

Further, regarding the issue of damages, the Court held:

> "Finally, because the development of any property in the watershed of a natural watercourse may add additional runoff to the stream, all of which may contribute to downstream damage, it would be unjust to impose liability on an owner for the damage attributable in part to runoff from property owned by others. Therefore, an owner who is found to have acted unreasonably and to have thereby caused damage to downstream property, is liable only for the proportion of the damage attributable to his conduct."

As a result of these holdings, and pending further appellate court decisions, it appears that the civil law natural watercourse rule has been modified by a rule of riparian reasonableness such that:

- Reasonable alteration (with "reasonableness" to include consideration of the purpose of the upstream improvement, the magnitude of the resulting flow changes, and the cost of mitigation measures available to both sides) avoids liability, even if the downstream owners acted reasonably. (Note: Logically the court followed *Keys* by resorting to the civil law rule where both parties act reasonably; but because the civil law rules are different for surface waters than for natural watercourses, the same logic leads to the opposite result).

- Lack of reasonable downstream mitigation arguably avoids liability, although more likely merely reduces the plaintiff's recoverable damages pursuant to the doctrine of damage mitigation discussed above.

- In any event, liability is only in proportion to causation, a rule which is easy to state but potentially difficult to apply.

(iii) Floodwaters

While the Supreme Court has not addressed the issue of a landowner's right to divert floodwaters since *Keys*, the arguably Draconian civil law rule of absolute immunity has long been qualified by at least some requirement of reasonableness, *Jones v. California Development Co.* (Calif. Sup. Ct. 1916) 173 Cal. 565; and post-*Keys* district appellate court decisions have readily concluded that a rule of reasonableness now applies.

For example, in both *Tahan v. Thomas* (DCA 1970) 7 Cal.App.3d 78 and *Linvill v. Perello* (DCA 1987) 189 Cal.App.3d 195, the appellate courts reversed trial court judgments which had been entered pursuant to the "public enemy" doctrine in favor of defendant landowners who had built dikes or levees to protect their property at the expense of their plaintiff neighbors, and sent the cases back to the trial courts for consideration of the issue of the reasonableness of the defendant's conduct.

b. Inverse condemnation (flood control projects).

Inverse condemnation liability for flood control projects involves the confluence of the post-*Albers* development of California's law of inverse condemnation, and the post-*Keys* development of California's drainage law. As discussed above, originally *Albers* recognized the *Archer* exception pursuant to which flood control projects were not subject to inverse condemnation liability for improvements for which the old civil law drainage rules granted immunity. After *Keys* qualified the absolute rights of the civil law rules with a rule of reasonableness, however, the *Archer* exception to inverse condemnation liability was no longer tenable.

The post-*Keys* California Supreme Court cases in which the "rule of reasonableness" drainage law changes have affected the applicability of inverse condemnation liability for flood control projects can be summarized as follows:[3]

[3] Ref. summary of "reasonableness" factors re: flood control projects, Appendix 6.

- In *Belair v. Riverside County Flood Control District* (Calif. Sup. Ct. 1988) 47 Cal.3d 550, in considering a case in which a flood control levee failed for reasons which the plaintiffs never explored (choosing to proceed solely on a strict liability inverse condemnation theory and not on a theory of negligence) and thereby flooded the historically flooded property which it had been built to protect, the Court:

  - Expressly limited the once arguably absolute *Archer* exception to only those cases in which the public entity acted "reasonably and non-negligently" stating that:

    > ". . . where the public agency's design, construction or maintenance of a flood control project is shown to have posed an unreasonable risk of harm to the plaintiffs, and such unreasonable design, construction or maintenance constituted a substantial cause of the damages, plaintiffs may recover regardless of the fact that the project's purpose is to contain the "common enemy" of floodwaters."

    Specifically, the Court held that ". . .when a public flood control improvement fails to function as intended, and properties historically subject to flooding are damaged as a proximate result thereof, the plaintiffs' recovery in inverse condemnation requires proof that the failure was attributable to some unreasonable conduct on the part of the defendant public entities."

  - Explained that "reasonableness" in this context "is not entirely a matter of negligence, but represents a balancing of the public need against the gravity of the private harm" so that "the reasonableness of the public agency's conduct must be determined on the facts of each individual case, taking into consideration the public benefit and the private damages in each instance."

  - Noted regarding "proximate cause" in the context of a flood control project that:

    > "Where independently generated forces not induced by the public flood control improvement -- such as a rainstorm -- contribute to the injury, proximate cause is established where the public improvement constitutes a substantial concurring cause of the injury, i.e., where the injury occurred in substantial part because the improvement failed to function as it was intended. The public improvement would cease to be a substantial contributing factor, however, where it could be shown that the damage

would have occurred even if the project had operated perfectly, i.e., where the storm exceeded the project's design capacity. In conventional terminology, such an extraordinary storm would constitute an intervening cause which supersedes the public improvement in the chain of causation."

- Observed that while the old "common enemy" doctrine did not confer a privilege to divert or obstruct waters from natural watercourses and therefore may never have been the subject of the old *Archer* exception: "It is doubtful, however, whether evidence of an unintended 'diversion' -- an elusive concept to begin with [cites] -- would elevate the test of inverse condemnation liability to absolute liability, rather than a reasonableness standard."

- In *Locklin v. County of Lafayette* (Calif. Sup. Ct. 1994) 7 Cal.4th 327 -- the same decision that extended the *Keys* rule of reasonableness from surface waters to natural watercourses as discussed above -- the Court:

  - Expounded upon the *Belair* holding that inverse condemnation liability would attach to unreasonable, but only unreasonable, aspects of a flood control project as follows:

    "We now hold that the privilege to utilize a natural watercourse for drainage of surface waters from improved public property and to make improvements in or alterations to a natural watercourse for the purpose of improving such drainage is a conditional privilege, not an absolute privilege. If an absolute privilege existed, downstream owners could be forced to bear a disproportionate share of the burden of improvements undertaken for the benefit of the public at large. A public agency may not impose on other riparian owners the burden of avoidable downstream damage if alternative or mitigating measures are available and the agency acts unreasonably in failing to utilize them. The privilege is conditional, however, in recognition that riparian property is subject to the natural watercourse rule as modified by the rule of reasonableness.

    * * *

    Today neither a private owner nor a public entity has the right to act unreasonably with respect to other property owners. Neither may disregard the interests of downstream property owners, and a public entity may no longer claim immunity in tort or inverse condemnation actions."

- Refined the *Belair* discussion of reasonableness in terms of a *Keys* balancing of interest by noting various specific factors to consider:

  "(1) The overall public purpose being served by the improvement project; (2) the degree to which the plaintiff's loss is offset by reciprocal benefits; (3) the availability to the public entity of feasible alternatives with lower risks; (4) the severity of the plaintiff's damage in relation to risk-bearing capabilities; (5) the extent to which damage of the kind the plaintiff sustained is generally considered as a normal risk of land ownership; and (6) the degree to which similar damage is distributed at large over other beneficiaries of the project or is peculiar only to the plaintiff"; and also "[r]easonableness in this context also considers the historic responsibility of riparian owners to protect their property from damage caused by the stream flow and to anticipate upstream development that may increase the flow."

- Expanded upon the *Belair* consideration of "proximate cause" by noting that "only damage caused by the improvement must be compensated" so that "a plaintiff in inverse condemnation must establish the proportion of damage attributable to the public entity from which recovery was sought"; and then underscored this point by upholding lower court findings that the defendants' drainage improvements could not have been a "substantial concurring cause of the damages suffered by plaintiffs" because they constituted too small a portion of the tributary area's overall urbanization.

- In *Bunch v. Coachella Valley Water District* (Calif. Sup. Ct. 1997) 15 Cal.4th 432, the Court returned to the issue left unresolved in *Belair* of whether the rule of reasonableness applied to natural watercourse improvements which involved actual diversion; and:

  - Expressly held that the rule of reasonableness applied even in diversion cases; and generally reaffirmed the *Belair* and *Locklin* application of the rule of reasonableness to flood control projects in general.

  - Expanded upon the factors to consider concerning "reasonableness" by expressly endorsing the consideration of a defendant public entity's budget limitations and needs to allocate limited funds among various worthy projects.

- Expressly left open the "question whether the reasonableness standard applies when flood control measures cause flood damage to land that was not historically subject to flooding"; but indicated that such a case would probably be subject to regular inverse condemnation rules (as two district courts of appeals have since held in *Akins v. State* (1998) 61 Cal.App.4th 1 and *Paterno v. State* (Nov. 2003) 2003 Cal.App. LEXIS 1771).

The current state of the applicability of inverse condemnation liability to flood control projects can with some confidence be summarized as follows:

- There is no liability for the failure of a "reasonable" flood control project to protect property historically subject to flooding; liability attaches to only the "unreasonable" aspects of a flood control project, with "reasonableness" being determined by a consideration of at least the factors prescribed by the Supreme Court as set forth above.

- Liability, if any, is for only that portion of the plaintiff's real property damages as the plaintiff can prove were substantially caused by the failed improvement; and there are no recoverable damages in cases where, for example, the design capacity of a flood control project is simply overwhelmed, or the improvement contributes only an insignificant portion of the damaging floodwaters.

- Regular inverse condemnation rules probably apply in a case in which even a "reasonable" flood control project diverts flood waters to property historically not subject to flooding.

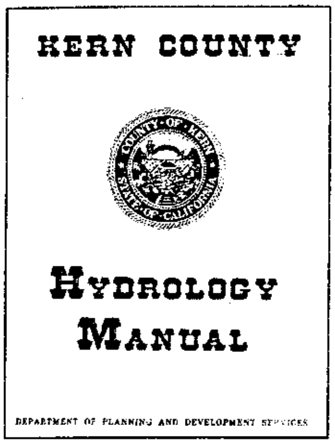
II. LITIGATIONWISE DRAINAGE DESIGN

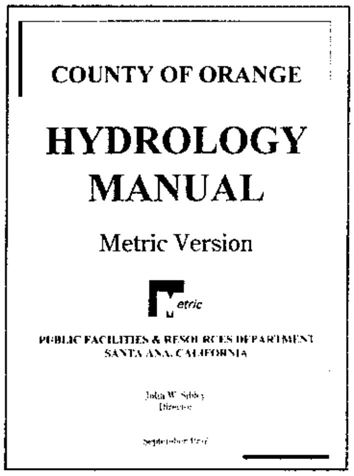
A. <u>Standard of Practice Drainage Design Issues</u>

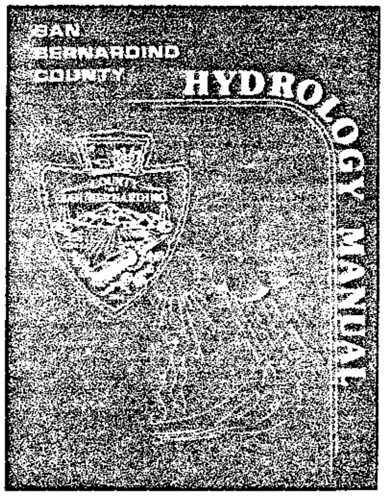
Theodore V. Hromadka, II, Ph.D., Ph.D., Ph.D., P.E., P.H.

Power Point Presentation

ISSUE: Designing Using the Peak Flow Rate – conservative or standard?







ISSUE: Effective Watershed in Calculating Peak Flow Rate – can part of the watershed produce a larger peak flow rate than the whole watershed?

Determine the effective area, peak discharge rate and time of concentration at the confluence of the three watersheds shown below in Figure 1.

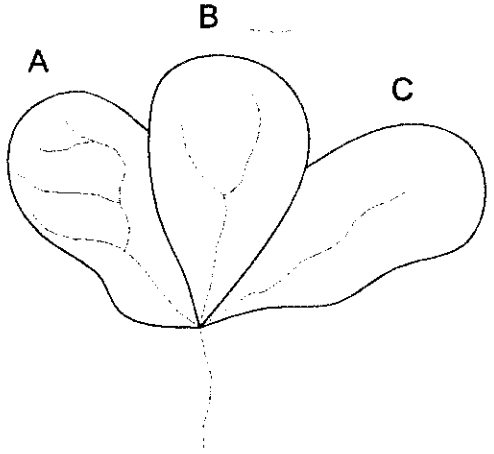


Figure 1

Watershed	Area (acres)	Time of Concentration (minutes)	Intensity (in. / hr)	Maximum Loss Rate (in. /hr.)	Discharge (cfs)
A	100	30	2.22	0.2	182
B	100	45	1.76	0.2	140
C	100	60	1.45	0.4	95

Effective Area

The effective area at the confluence is dependent on the time of concentration. For example only a portion of watersheds B and C are contributing runoff to the confluence at a 30 minute time of concentration. Following are calculations for the three watershed T_c's. It is noted that the estimation of the effective catchment area is only an approximation, and should be verified by the hydrologist.

Time of Concentration (minutes)	Watershed A Effective Area (acres)	Watershed B Effective Area (acres)	Watershed C Effective Area (acres)	Total Effective Area (acres)
30	100	(30min/45min)100	(30min/60min)100	217
45	100	100	(45min/60min)100	275
60	100	100	100	300

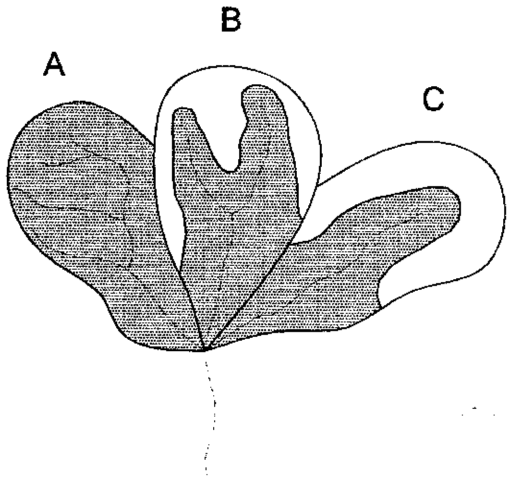


Figure 2: Effective area for T_c of 30 minutes.

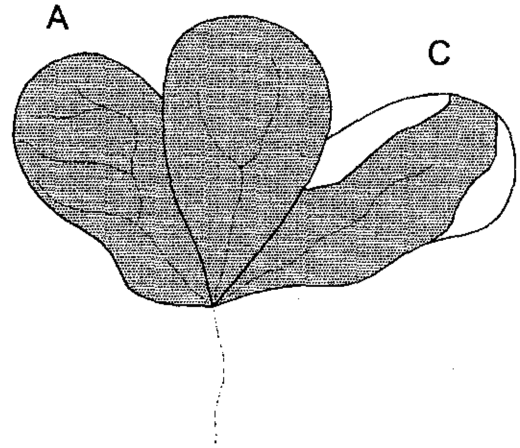


Figure 3: Effective area for T_c of 45 minutes.

Peak Discharge Rate

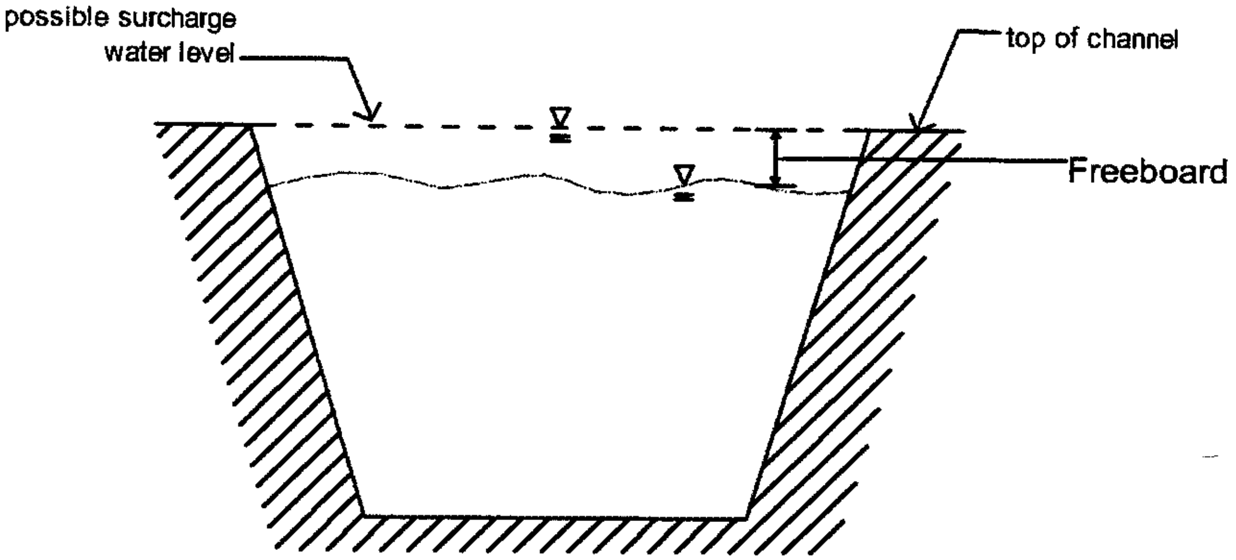
The peak discharge rate is also calculated for the three times of concentration as shown below.

Concentration (minutes)	Watershed A Peak Discharge Rate (cfs)	Watershed B Peak Discharge Rate (cfs)	Watershed C Peak Discharge Rate (cfs)	Confluence Peak Discharge Rate (cfs)
30	182	0.9(2.22 – 0.2)66.67*Ac	0.9(2.22 – 0.4)50*Ac	386
45	0.9(1.76 – 0.2)100*Ac	140	0.9(1.76 – 0.4)75*Ac	372
60	0.9(1.45 – 0.2)100*Ac	0.9(1.45 – 0.2)100*Ac	95	320

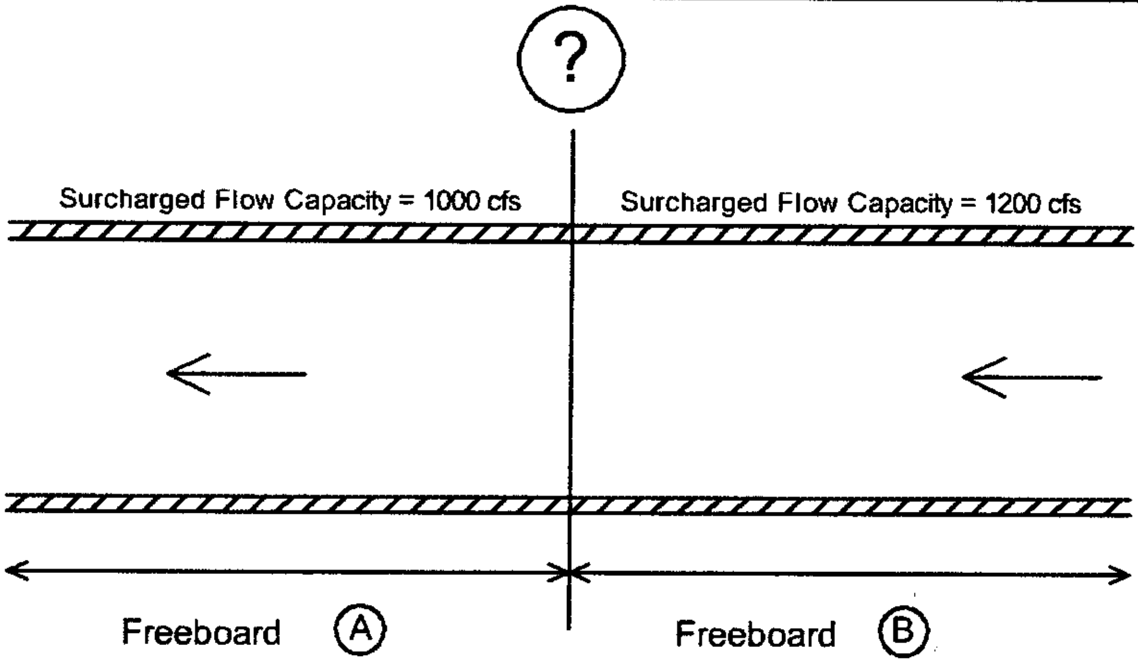
Time of Concentration

Generally the time of concentration corresponding to the largest confluenced peak discharge rate is chosen. However the hydrologist should inspect the entire catchment hydrology to ensure the appropriate confluence data is used. For example, if a large subarea is to be added immediately downstream of a confluence, then it may be appropriate to select the confluence data with a slightly smaller peak rate of discharge and a significantly smaller time of concentration because the addition of the large subarea immediately downstream of the confluence will generate a higher peak discharge rate with the smaller time of concentration.

ISSUE: Freeboard in Channels -- extra capacity for carrying flows?

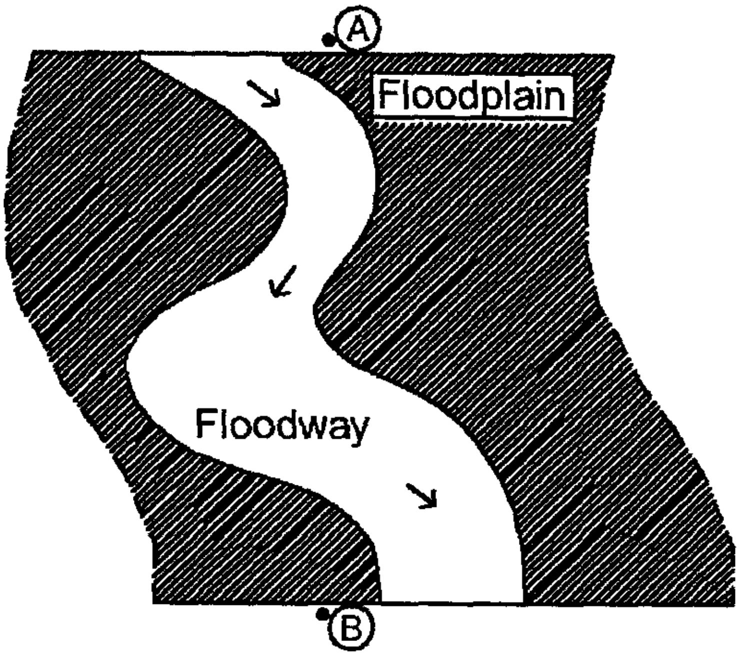


Freeboard Concepts

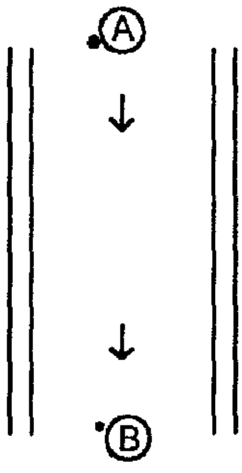


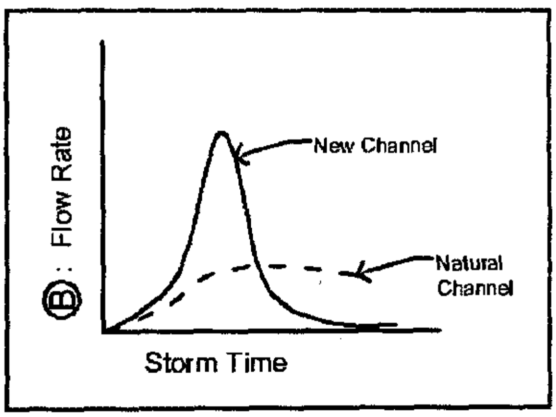
Imbalanced Freeboard Implications
(Freeboard (B) greater than Freeboard (A))

ISSUE: Loss of NATURAL STORAGE -- drainage channels increase runoff flow rates due to loss of natural storage?



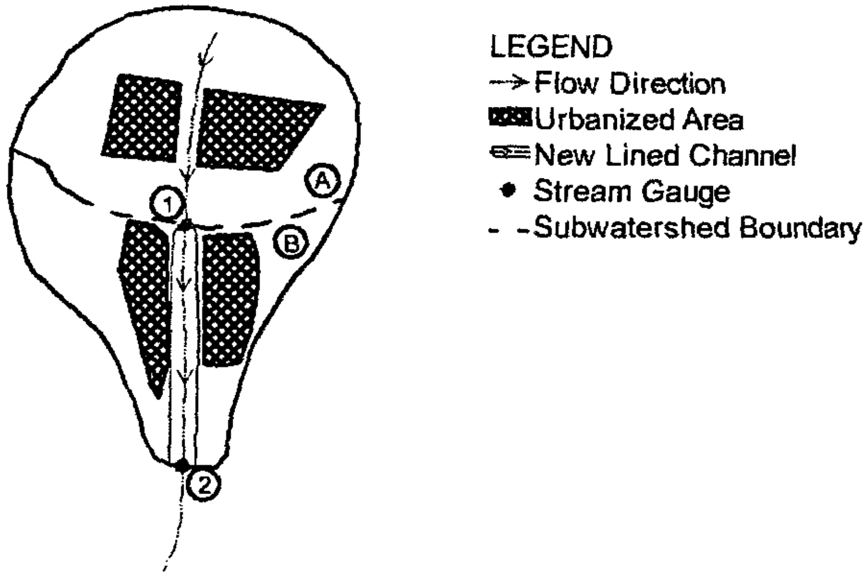
Natural Water Course with Significant Natural Storage

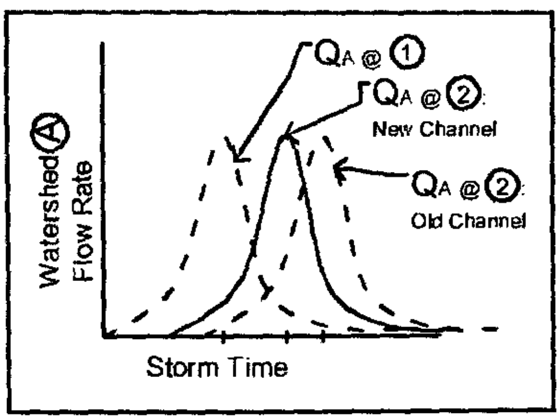


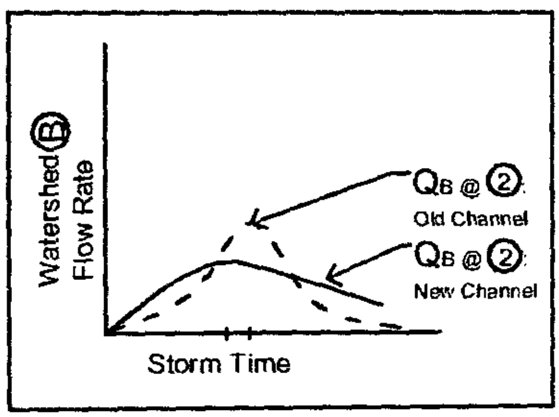


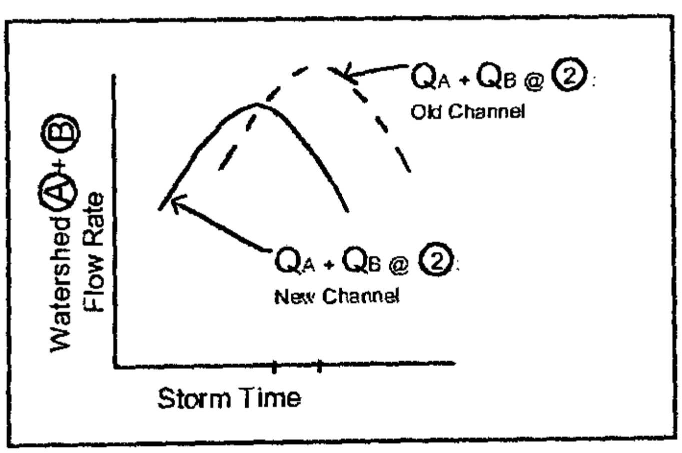
New Channel: Steeper, Shorter Path, Much Less Storage Effects

ISSUE: More Efficient Channel Systems -- does lining of channels always increase flow rates?

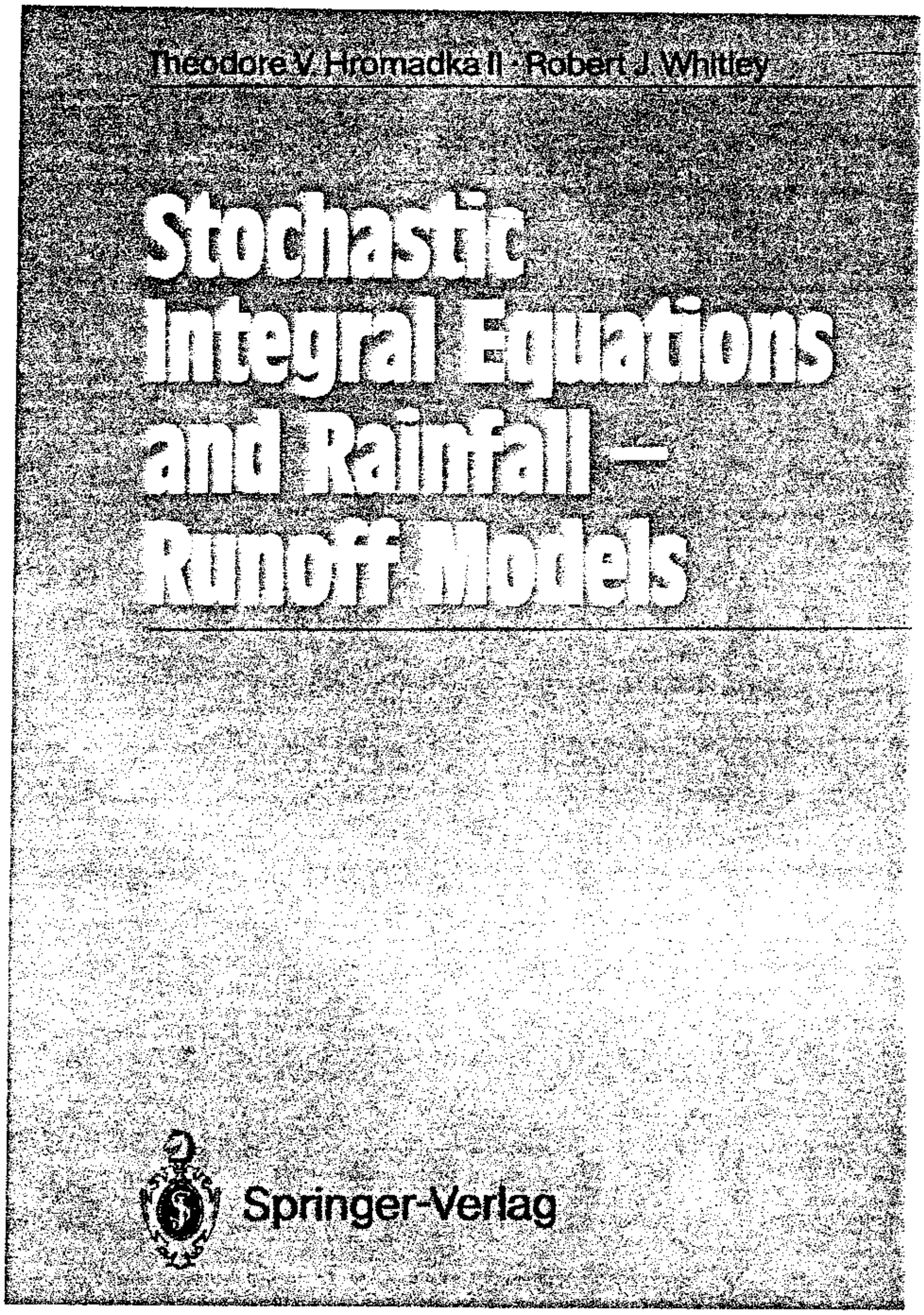








ISSUE: Watershed Computer Modeling -- does increased complexity in computer models produce more accurate results in estimating flood flows?



Stormflow Determination Methods

When studying a watershed for severe storm runoff characteristics, the usual procedure is to collect data on precipitation, soil types, stream discharge, and other hydrologic and geologic characteristics. This data may then be evaluated in accordance with theory presented in standard texts. Although precipitation and streamflow data are available at selected locations throughout the country (for example the U.S. Weather Service and the U.S. Geological Survey), sufficient data are usually unavailable for local watersheds to develop precise hydrologic calculations. More importantly, the long-term effects on flood hydrology due to urbanization of the watershed are usually not precisely represented by the available data. For these reasons, synthetic flood hydrology methods are usually required. And since the introduction of digital computers, literally hundreds of hydrologic models have been produced.

Method for Development of Synthetic Flood Frequency Estimates

The uses of flood flow frequency data range from the specification of flood insurance risk relationships to the commonly occurring problem of designing flood control facilities. Typically, however, stream gauge data are usually unavailable at the study site; consequently, some type of method is needed to synthesize a flood frequency curve for ungauged streams.

The various types of procedures used to develop flow frequency estimates at ungauged locations can be grouped as follows: (1) Data transfer methods, (2) Statistical methods, (3) Empirical equations, and (4) Simulation models.

Because flood flow frequency information is used for various purposes, the hydrologist must be aware of the limitations and factors involved which are associated with each of the groupings of methods. For example, flood flow frequency estimates used for design of flood control facilities often are conservative in that the design discharges are high for the corresponding return frequency. In this fashion, the designer compensates for the unknown reliability of the design flow rate and provides for a factor of safety. For flood insurance studies, however, use of the computed flood flow frequency estimate may be desirable in order to avoid excessively high costs for the corresponding benefit (see U.S. Army Corps of Engineers Training Document No. 11, TD-11, 1980).

Detailed discussions of the several categories of flood flow frequency analysis procedures are contained in TD-11. In that publication, the four groupings of methods are further defined into eight categories as follows:

(I) statistical estimation of peak flowrates
(II) statistical estimation of moments
(III) index flood estimation methods
(IV) transfer methods
(V) empirical equations
(VI) single event methods
(VII) multiple discrete event methods
(VIII) continuous simulation methods.

Advantages and disadvantages of methods in each of these eight categories are discussed in the following paragraphs.

Category I: Statistical estimation of peak flowrate (Q_P) methods use regression equations for determining a specific return frequency of flowrate by correlating stream gauge data to watershed characteristics. Ungauged stream flowrate estimates can then be obtained from the regression equations. Table 1 (TD-11, 1980) compares the advantages and disadvantages associated with this category of methods.

Category II: The statistical estimation of moments procedure extends the procedures of Category I by correlating the statistical moments of the frequency function developed from the stream gauge data to watershed characteristics. Table 2 (TD-11, 1980) lists the advantages and disadvantages of this category of methods.

Category III: Index flood estimation methods (see Table 3) are analogous to the above two categories except that a selected index flood, such as the mean annual event, is used for the development of the necessary statistical relationships for events other than the index event.

TABLE 1
STATISTICAL ESTIMATION OF Q_P
(CATEGORY I)
Reference: TD-11 (1980)

Applicability/Advantages	Limitations/Disadvantages
• Procedures are based on accepted statistical methods.	• Requires knowledge of both statistics and hydrology in derivation and utilization.
• Procedures are available for most of the country.	• Procedures require numerous regression analyses and are time consuming to develop.
• Reliability of the prediction equations is known for gauged areas used in derivation.	• Only provides estimates of specific peak flood flow frequency relationships.
• Estimates are reliable for hydrologically similar basins as those used in the derivation.	• Cannot evaluate effects resulting from modifications in the system (physical works and alternative land use patterns).
• Once developed, the procedure is quick and easy to use.	• Procedures are often misused by application for areas with different stream patterns and other hydrologic characteristics from the gauged locations used in the derivation.
• Permits direct calculation of specific peak flood flow frequency estimates that are individually and statistically derived.	• Cannot adequately evaluate hydrologically unique areas in the region.
• Procedures may be used in conjunction with other procedures such as to provide calibration relationships for simulation models.	• Easy to use therefore may be used where other methods would be more appropriate.
• Provides a quick check for reasonableness for situations requiring use of other procedures.	• Derivation requires several hydrologically similar gauged basins in the region.
	• Does not assume a distribution; hence reliability confidence limits cannot be calculated.

TABLE 2
STATISTICAL ESTIMATION OF Q_P
(CATEGORY II)
Reference: TD-11 (1980)

Applicability/Advantages	Limitations/Disadvantages
• Procedures are based on accepted statistical methods.	• Requires knowledge of both statistics and hydrology in derivation and utilization.
• The entire frequency function is developed from the three moments; means, standard deviation and skew.	• Procedure requires regression analysis for the two or three moments of the frequency.
• Reliability of the prediction equations is known for gauged areas used in derivation.	• May be time consuming to develop.
• Estimates are as reliable for hydrologically similar basins as those used in derivation.	• Does not calculate specific flood flow frequency events.
• Once developed, the procedure is quick and easy to use.	• Only provides estimates of peak flood flow frequency relationships.
• Procedures may be used in conjunction with other procedures, such as, to provide calibration results for simulation models.	• Cannot evaluate effects resulting from modifications in the system (physical works and alternate land use patterns).
• Provides a quick check for reasonableness for situations requiring use of other procedures.	• Cannot adequately evaluate many complex river systems.
	• Cannot evaluate hydrologically unique areas in the region.
	• Ease of use may result in improper application.
	• Derivation requires several hydrologically similar gauged basins in the region.

TABLE 3
INDEX FLOOD ESTIMATE
(CATEGORY III)
Reference: TD-11 (1980)

Applicability/Advantages	Limitations/Disadvantages
• Procedure is easier to develop than other statistical methods, and has only one regression analysis.	• Procedure yields same variance (slope of frequency curve) for all applications.
• Procedures are commonly used and based on accepted statistical methods.	• Probably least accurate of the statistical procedures.
• Reliability of prediction equation for index flood is known for derivation.	• Requires knowledge of both statistics and hydrology in derivation and utilization.
• Estimates are reliable for hydrologically similar basins as those used in derivation.	• May be time consuming to develop.
• Once developed, the procedure is quick and easy to use.	• Only provides estimates of peak flood flow frequency relationships.
• Procedures may be used in conjunction with other procedures, such as, to provide calibration results for simulation models.	• Cannot evaluate effects resulting from modifications in the system (physical works and alternative land use patterns).
• Provides a quick check for situations requiring use of other procedures.	• Cannot adequately evaluate many complex river systems.
	• Cannot evaluate hydrologically unique areas in the region.
	• Ease of use may result in improper application.
	• Derivation requires several hydrologically similar gauged basins in the region.

Category IV: Transfer methods (Table 4) usually refer to the relationships used to estimate flowrates immediately upstream or downstream of a stream gauge location. However TD-11 broadens this category to include procedures for the direct transfer of peak flood flow frequency values or frequency functions from similar gauge locations to the subject study point.

Category V: Empirical equations are often used for the estimation of peak flowrates. The well-known rational method is an important example of this category. Table 5 (TD-11) compares the advantages and disadvantages of this group of methods.

Category VI: Single event methods are the most widely used approach for developing runoff hydrographs which are subsequently used to develop a flood flow frequency curve. Incorporated in this category are the design storm methods which attempt to relate runoff and rainfall frequency curves. Table 6 from TD-11 examines several features of this category of methods.

Category VII: By considering a series of important record storm events with a single event method, an approximate flood frequency curve can be developed. The multiple discrete event category (see Table 7) of models serves as a blend of the single event category of models and the concept of continuous simulation.

Category VIII: Continuous simulation (or continuous record) models attempt to develop a continuous streamflow record based on a continuous rainfall record. Although in concept this category (see Table 8) of models appears to be plausible, the success of these methods has not been clearly established due to the lack of evidence that this approach out performs the much simpler and more often used unit hydrograph procedures of Category VI.

TABLE 4
TRANSFER METHODS
(CATEGORY IV)
Reference: TD-11 (1980)

Applicability/Advantages	Limitations/Disadvantages
(WRC Transfer of Q_P)	(WRC Transfer of Q_P)
• Procedure us easy and quick to use.	• Ease of use may result in improper application.
• Provides reliable estimates immediately upstream and downstream of gauge location if hydrologic characteristics are consistent.	• Can only be utilized immediately upstream and downstream of gauged area where hydrologic characteristics are consistent.
• Procedure is commonly used and generally acceptable.	
(Direct Transfer)	(Direct Transfer)
• Provides quick estimate where time constraints are binding and other procedures are not applicable.	• Estimates are not accurate enough for most analysis requirements.
• Can readily be used as a check for reasonableness of results from other procedures.	• Cannot be used for modified basin conditions.
• Provides valuable insight as to the regional slope characteristics of the flood flow frequency relationships.	• Can only be used as check in areas where hydrologic characteristics are nearly similar and with drainage areas within the same order of magnitude.

TABLE 5
EMPIRICAL EQUATIONS
(CATEGORY V)
Reference: TD-11 (1980)

Applicability/Advantages	Limitations/Disadvantages
• Provides quick means of estimating peak discharge frequency for small areas. • Concepts can be understood by nonhydrologists. • Suitable for many types of municipal engineering analyses (storm sewers, culverts, small organizations impacts, etc.). • Familiarity of procedures and use had led to politically acceptable solutions for small areas. • Can be used as a check for reasonableness of more applicable procedures in small areas.	• Generally are not applicable for areas greater than one square mile. • Estimate only the peak discharge frequency relationships. • Cannot be used to design storage facilities. • Cannot adequately evaluate complex systems where timing and combining of flood hydrographs are important.

TABLE 6
SINGLE EVENT SIMULATION
(CATEGORY VI)
Reference: TD-11 (1980)

Applicability/Advantages	Limitations/Disadvantages
• Generates other hydrologic information rather than peak discharges (volumes, time to peak, rate of rise, etc.).	• Balanced flood concept is difficult to understand.
• Generates balanced floods as opposed to historically generated events which may be biased.	• Modeling requires more time, data, and resources (costs) than statistical procedures.
• Enables evaluation of complex systems and modifications to the watersheds.	• Hydrologists must understand the concepts utilized by the model.
• Provides good documentation for quick future use.	• Requires calibration to assure rainfall frequency approximates runoff frequency.
• Uses fewer parameters than most continuous simulation models.	• Unit hydrograph assumes a linear relationship with runoff.
• Approximates the hydrologic runoff process as opposed to statistical methods.	• Requires data processing capabilities.
• Procedures are more economical than continuous simulation procedures.	• Procedures greatly simplify the hydrologic process.
• Calibration procedures are easier than continuous simulation models.	• Procedures are generally limited to basins greater than one square mile.
• Models may be calibrated to either simple or complex systems.	• Parameters are difficult to obtain for existing and modified conditions.
	• Difficult to obtain antecedent moisture conditions.
	• Depth-area of rainfall varies with drainage area size.

TABLE 7
MULTIPLE DISCRETE EVENTS
(CATEGORY VII)
Reference: TD-11 (1980)

Applicability/Advantages	Limitations/Disadvantages
• Concepts are easier to understand than those associated with hypothetical frequency events. • Antecedent moisture conditions are determined. • Depth-area precipitation problems are eliminated. • Evaluates fewer events than continuous simulation models. • Enables evaluations of complex systems and physical modifications in the watershed. • Uses fewer parameters than continuous simulation models. • Approximates hydrologic process as opposed to statistical methods. • Provides good documentation for future use.	• Requires numerous storm analyses and subsequent event analyses. • Important events may be overlooked. • Results may be biased by historic records. • Procedures use simplified hydrologic process. • Requires data processing capabilities. • Parameters are difficult to obtain. • Unit hydrograph assumes linear relationship with runoff. • Requires calibration which is more time consuming than single event due to the large number of events that are processed. • Procedure is significantly more expensive than single event modeling. • Procedures generally not feasible for small study areas, short time constraints, etc.

TABLE 8
CONTINUOUS SIMULATION
(CATEGORY VIII)
Reference: TD-11 (1980)

Applicability/Advantages	Limitations/Disadvantages
• Concepts are easily understood.	• The calibration process is extensive and generally must be performed by qualified experienced hydrologists.
• Concepts are more physically based than other procedures.	• Procedures are expensive and time consuming to use, impractical for moderate or small resources allocated projects.
• Antecedent moisture conditions are automatically accounted for.	• The results may be biased by the use of historic rainfall data.
• Can be used in unique basins where other procedures such as statistical procedure are not applicable.	• The procedures require large analytical processing capabilities.
• Process analyses in single computer runs as numerous discrete events.	• The models typically require a large amount of data to properly define the parameters.
• Can automatically determine annual peak floods at various locations even if their frequencies are different.	
• Can model the effects of complex systems and physical works.	

Watershed Modeling Uncertainty

Watershed runoff is a function of rainfall intensity, the storm duration, the infiltration capacity of the soil, the cover of the soil, type of vegetation, area of the watershed and related shape factors, distribution of the storm with respect to space and time, watershed stream system topology, connectivity and branching, watershed geometry, stream system hydraulics, overland flow characteristics, and several other factors. Because of the dozens of variables which are included in a completely deterministic model of watershed runoff and due to the uncertainty which is associated to the spatial and temporal values of each of the various mathematical definitions, urban hydrologists need to include a measure of uncertainty in predicting surface runoff quantities.

With the widespread use of minicomputers and inexpensive microcomputers, the use of deterministic models is commonplace. These models attempt to simulate several of the most important hydrologic variables that strongly influence the watershed runoff quantities produced from severe design storm events. Generally speaking, the design storm (e.g., single event) and continuous simulation models include approximations for runoff hydrograph generation (coupled with models for estimating interception, evapotranspiration, interflow, and infiltration), channel routing, and detention basin routing. The computer program user then combines these processes into a link-node schematic of the watershed. Because each of the hydrologic processes involves several parameters, the resulting output of the model, the runoff hydrograph, may be a function of several dozen parameters. In a procedure called calibration, many or all of the parameters are estimated by attempts to duplicate significant historical runoff hydrographs. However, Wood (1976) notes that the watershed model parameter interaction can result in considerable difficulty in optimizing the parameter set. In a similar deterministic modeling approach for soil systems and soil water movement, Guymon et al. (1981) found that just the normal range of uncertainty associated with laboratory measurement of groundwater flow hydraulic parameters can produce considerable variation in the model output. A detailed analysis of the sensitivity corresponding to a watershed model is given by Mein and Brown (1978). Because of the vast spectrum of rainfall-runoff models available today, it is appropriate to review some of the comments noted in the literature as to the relative success of rainfall-runoff models in solving the runoff estimation problem in a purely deterministic setting.

Some Concerns in Deterministic Rainfall-Runoff Model Performance

Due to the need for developing runoff hydrographs for design purposes, statistical methods such as those contained in model categories I-V are usually precluded in watershed hydrologic studies. Consequently, the categories of models available are essentially restricted to categories VI, VII, and VIII. The "single event" models directly transform a design storm (hypothetical causative input) into a flood hydrograph. The "multiple discrete event" models transform an annual series of selected discrete rainfall events (usually one storm for each year) into an annual series of runoff hydrographs whose peak flowrates are used for subsequent statistical analysis. The "continuous record" or "continuous simulation" model results in a continuous record of synthetic runoff hydrographs for statistical synthesis. Each of the above three categories of deterministic models contain various versions and modifications which range widely in complexity, data requirements, and computational effort.

In general, the well-known unit hydrograph design storm approach has continued widespread support among practitioners and governmental agencies involved in flood control design. Such general purpose models include the U.S. Department of Agriculture, Soil Conservation Service or SCS model (1975) and the U.S. Army Corps of Engineers (HEC) hydrology computer program package (see TD-15, 1982). In a recent survey of hydrologic model usage by Federal and State governmental agencies and private engineering firms (U.S. Department of Transportation, Federal Highway Administration Hydraulic Engineering Circular No. 19, October, 1984), it was found that "practically no use is made of watershed models for discrete event and continuous hydrograph simulation." In comparison, however, design storm methods were used from 24 to 34 times more frequently than the discrete event or continuous simulation models by Federal agencies and the private sector, respectively. The frequent use of design storm methods appears to be due to several reasons: (1) design storm methods are considerably simpler to use than discrete event and continuous simulation models; (2) it has not been established in general that the more complex models provide an improvement in computational accuracy over design storm models; and (3) the level of complexity typically embodied in the continuous simulation class of models does not appear to be appropriate for the catchment rainfall-runoff data which is typically available. Consequently, the design storm approach continues to be the most often selected for flood control and drainage design studies.

A criterion for classifying a model as being simple or complex is given by Beard and Chang (1979) as the "difficulty or reliability of model calibration.... Perhaps the simplest type of model that produces a flood hydrograph is the unit hydrograph model"...and... "can be derived to some extent from physical drainage features but fairly easily and fairly reliably calibrated through successive approximations by relating the time distribution of average basin rainfall excess to the time distribution of runoff." In comparison, the "most complicated type of model is one the represents each significant element of the hydrologic process by a mathematical algorithm. This is represented by the Stanford Watershed Model and requires extensive data and effort to calibrate."

The literature contains several reports of problems in calibrating complex models, especially in parameter optimization. Additionally, it has not been clearly established whether complex models, such as in the continuous simulation or discrete event classes of models, provide an increase in accuracy over a simple single event unit hydrograph model. There are only a few papers and reports in the literature that provide a comparison in hydrologic model performance. From these references, it appears that a simple unit hydrograph model oftentimes provides estimates of runoff quantities which are comparable to considerably more complex rainfall-runoff models.

In their paper, Beard and Chang (1979) write that in the case of the unit hydrograph model, "the function of runoff versus rainfall excess is considered to be linear, whereas it usually is not in nature. Also, the variations in shapes of unit hydrographs are not derivable directly from physical factors. However, models of this general nature are usually as representative of physical conditions as can reasonably be validated by available data, and there is little advantage in extending the degree of model sophistication beyond validation capability."

Schilling and Fuchs (1986) write "that the spatial resolution of rain data input is of paramount importance to the accuracy of the simulated hydrograph" due to "the high spatial variability of storms" and "the amplification of rainfall sampling errors by the nonlinear transformation" of rainfall into runoff. Their recommendations are that a rainfall-runoff model should employ a simplified surface flow model if there are many subbasins; a simple runoff coefficient loss rate; and a diffusion (zero inertia) or storage channel routing technique.

In attempting to define the modeling processes by the available field data forms, Hornberger et al (1985) find that "Hydrological quantities measured in the field tend to be either integral variables (e.g., stream discharge, which reflects an integrated catchment response) or point estimates of variables that are likely to exhibit marked spatial and/or temporal variation (e.g., soil hydraulic conductivity)." Hence, the precise definition of the physics in a modeling sense becomes a problem that is "poorly posed in the mathematical sense." Typically, the submodel parameters cannot be estimated precisely due to the large associated estimation error. "Such difficulties often indicate that the structural complexity of the model is greater than is warranted on the basis of the calibration data set." It was also noted by Hornberger et al (1985) that success in rainfall-runoff modeling "has proved elusive because of the complexity of the processes, the difficulty of performing controlled experiments, and the spatial and temporal variability of catchment characteristics and precipitation." They concluded that "Even the most physically based models…cannot reflect the true complexity and heterogeneity of the processes occurring in the field. Catchment hydrology is still very much an empirical science."

Schilling and Fuchs (1986) note that errors in rainfall-runoff modeling occur for several reasons, including:

"1. The input data, consisting of rainfall and antecedent conditions, vary throughout the watershed and cannot be precisely measured.
1. The physical laws of fluid motion are simplified.
2. Model parameter estimates may be in error."

By reducing the rainfall data set resolution from a grid of 81 rain gauges to a single catchment-centered rain gauge in an 1,800 acre catchment (Fig. 1), variations in runoff volumes and peak flows "is well above 100 percent over the entire range of storms implying that the spatial resolution of rainfall has a dominant influence on the reliability of computed runoff." It is also noted that "errors in the rainfall input are amplified by the rainfall-runoff transformation" so that "a rainfall depth error of 30 percent results in a volume error of 60 percent and a peak flow error of 80 percent." Schilling and Fuchs

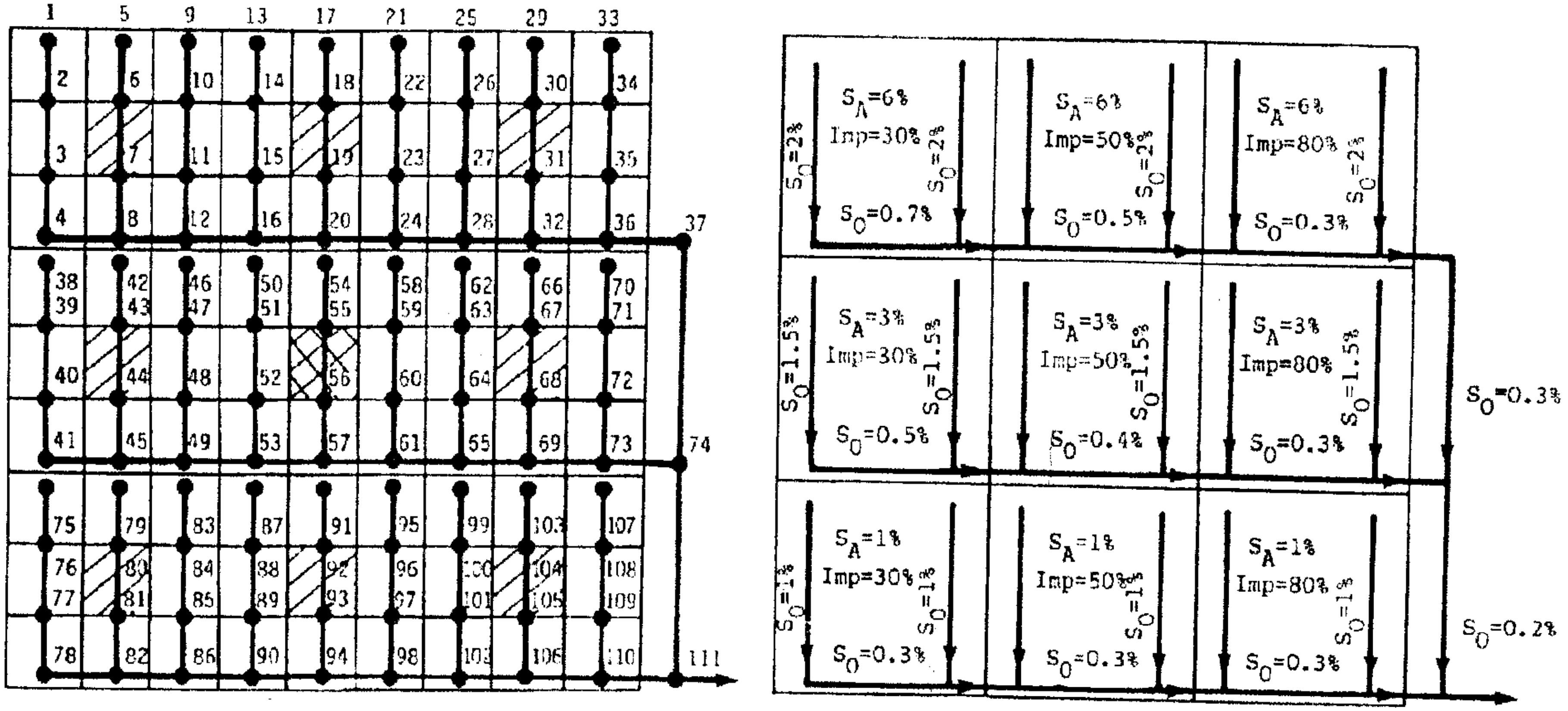


Figure 1: The Schilling and Fuchs Study Catchment

(1986) also wrote that "it is inappropriate to use a sophisticated runoff model to achieve a desired level of modeling accuracy if the spatial resolution of rain input is low."

Similarly, Beard and Chang (1979) write that in their study of 14 urban catchments, complex models such as continuous simulation typically have 20 to 40 parameters and functions that must be derived from recorded rainfall-runoff data. "Inasmuch as rainfall data are for scattered point locations and storm rainfall is highly variable in time and space, available data are generically inadequate…for reliably calibrating the various interrelated functions of these complex models." Additionally, "changes in the model that would result from urbanization could not be reliably determined." Beard and Chang (1979) write that the application "of these complex models to evaluating changes in flood frequencies usually requires simulation of about 50 years of streamflow at each location under each alternative watershed condition."

Garen and Burges (1981) noted the difficulties in rainfall measurement for use in the Stanford Watershed Model, because the K1 parameter (rainfall adjustment factor) and UZSN parameter (upper level storage) had the dominant impact on the model sensitivity. This is especially noteworthy because Dawdy and O'Donnell (1965) concluded that insensitive model coefficients could not be calibrated accurately. Thus, they could not be used to measure physical effects of watershed changes.

In the extensive study by Loague and Freeze (1985), three event-based rainfall-runoff models (a regression model, a unit hydrograph model, and a kinematic wave quasi-physically based model) were used on three data sets of 269 storm events from three small upland catchments. In that paper, the term "quasi-physically based" or QPB is used for the kinematic wave model. The three catchments were 25 acres, 2.8 square-miles, and 35 acres in size, and were extensively monitored with rain gauge, stream gauge, neutron probe, and soil parameter site testing.

For example, the 25 acre site instrumentation (Fig. 2) contained 35 neutron probe access sites, 26 soil parameter sites (all equally spaced), an on-site rain gauge, and a stream gauge. The QPB model (Fig. 3) utilized 22 overland flow planes and four channel segments. In comparative tests between the three modeling approaches to measured rainfall-runoff data it was concluded that all models performed poorly and that the QPB performance was only slightly improved by calibration of its most sensitive parameter, hydraulic conductivity. They write that the "conclusion one if forced to draw…is that the QPB model does not represent reality very well; in other words, there is considerable model error present. We suspect this is the case with most, if not all conceptual models currently in use." Additionally, "the fact that simpler, less data intensive models provided as good or better predictions that a QPB is food for thought."

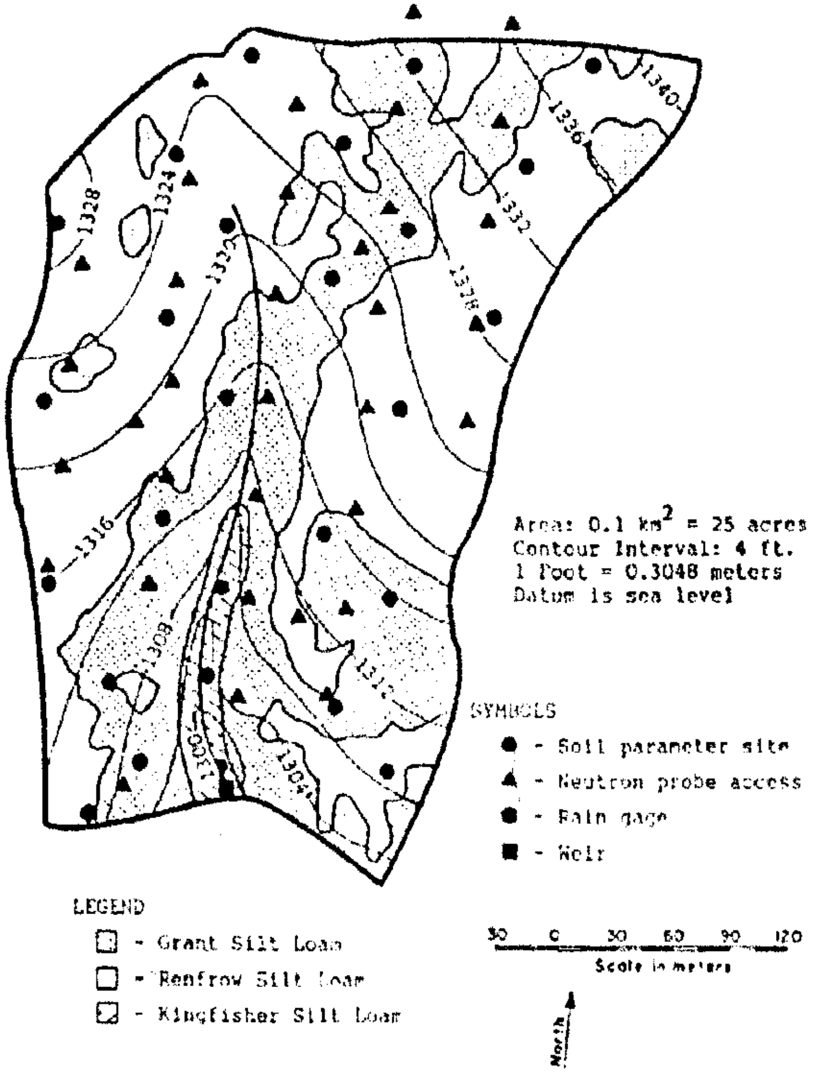


Figure 2: The Loague and Freeze (1985) Study Watershed

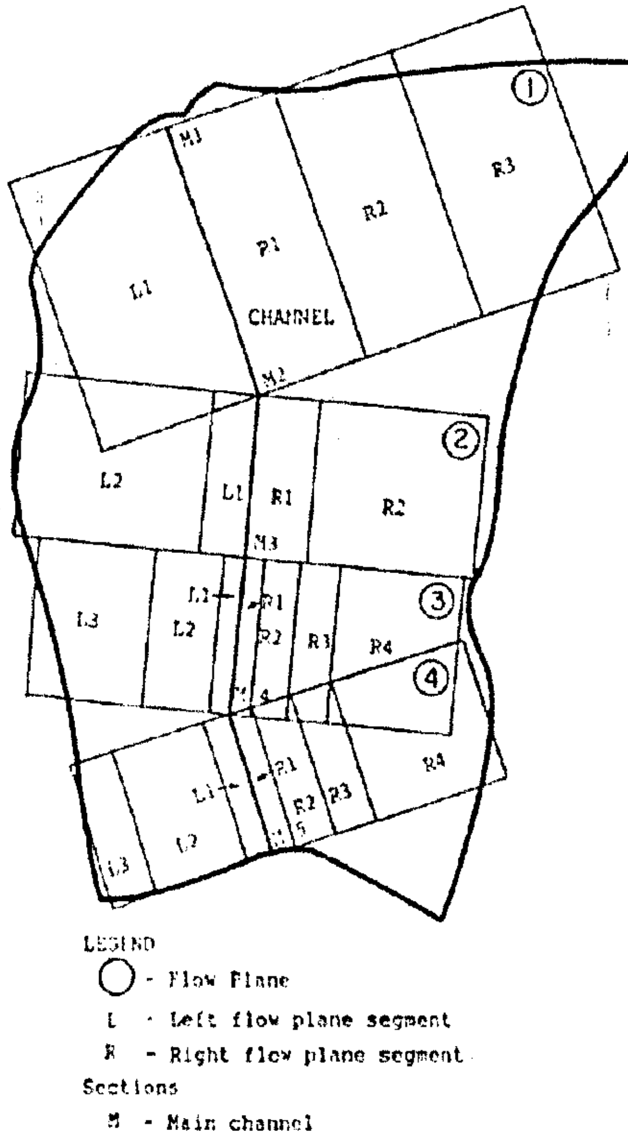
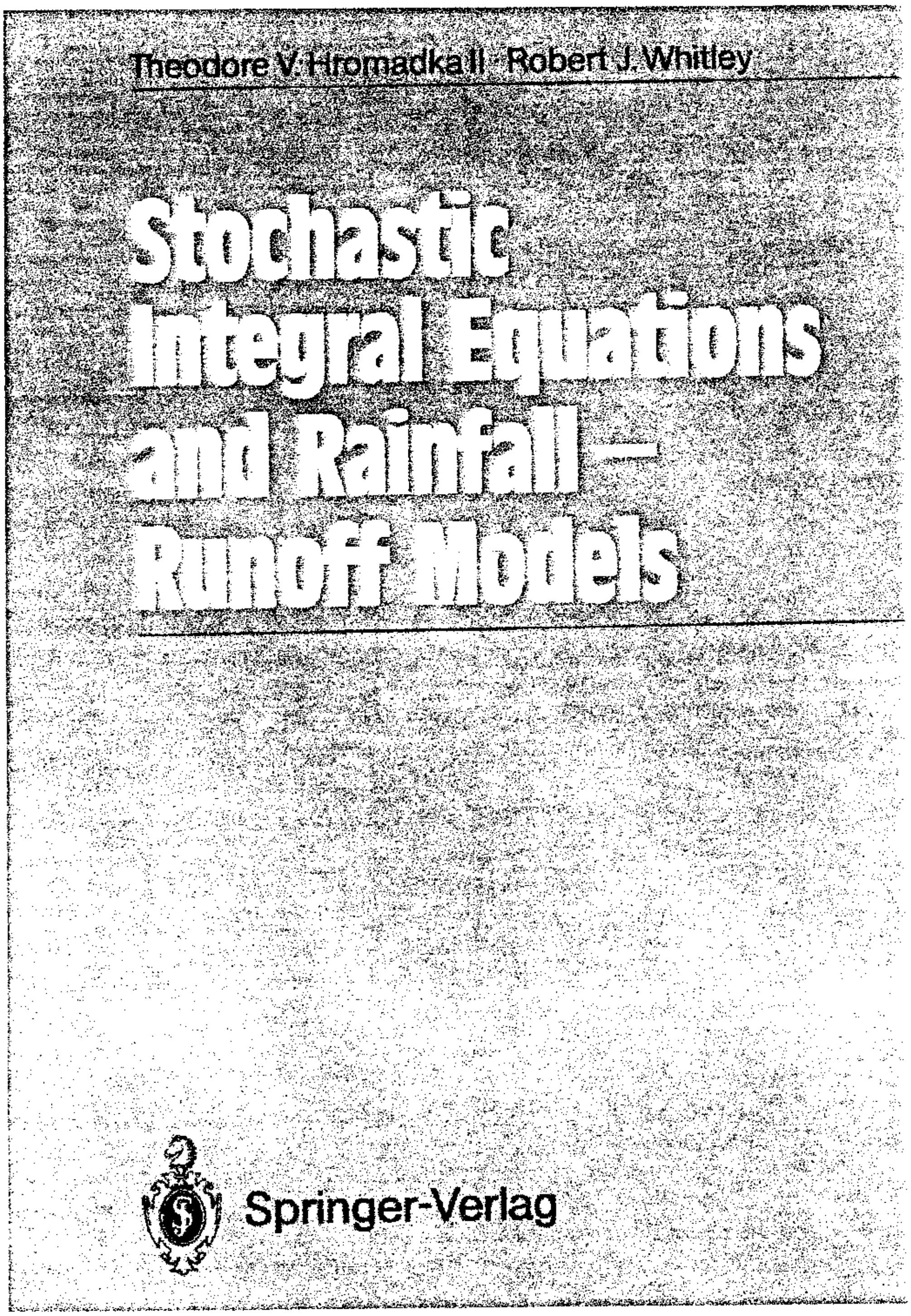


Figure 3: Loague and Freeze (1985) Quasi-Physically Based Model Schematic

ISSUE: Watershed Model Calibration -- do the modeling results represent reality?

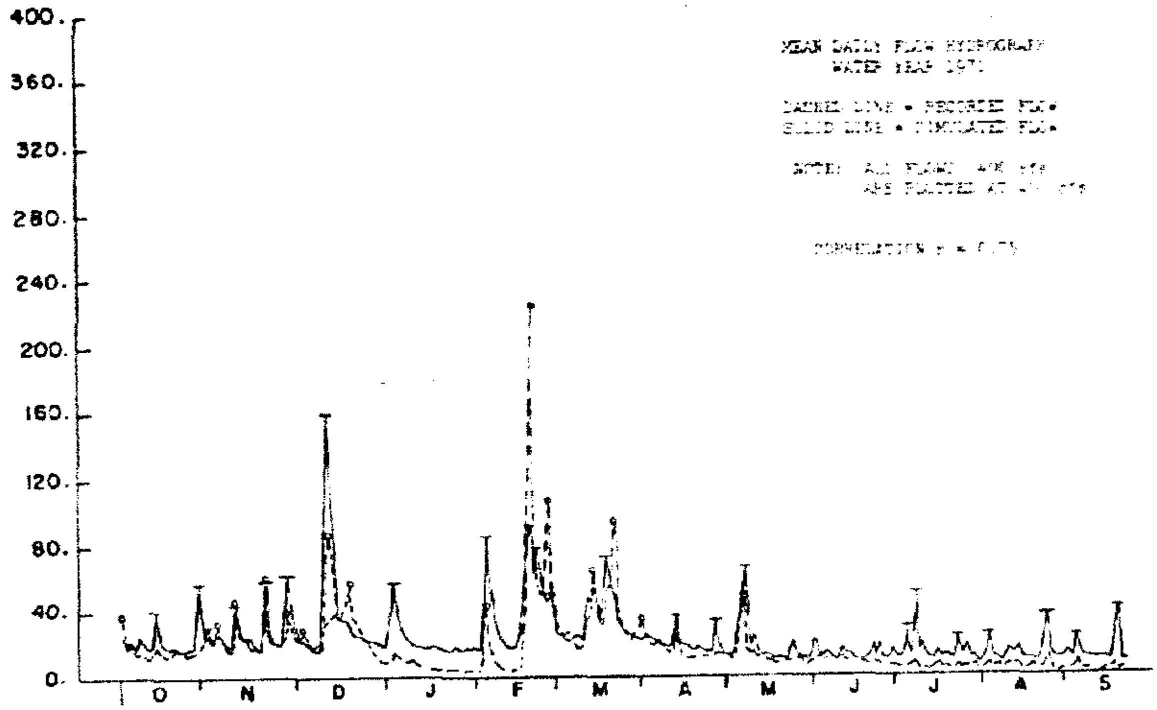


Based on the literature, a major difficulty in the use, calibration, and development of rainfall-runoff models appears to be the lack of precise rainfall data and the high model sensitivity to (and magnification of) rainfall measurement errors. Nash and Sutcliffe (1970) write that "As there is little point in applying exact laws to approximate boundary conditions, this, and the limited ranges of the variables encountered, suggest the use of simplified empirical relations."

It is noteworthy to consider the HEC Research Note No. 6 (1979) where the Hydrocomp HSP continuous simulation model was applied to the West Branch DuPage River in Illinois. Personnel from Hydrocomp, HEC (U.S. Army Corps of Engineers, Hydrologic Engineering Center) and COE (U.S. Army Corps of Engineers) participated in this study which started with a nearly complete hydrologic/meteorologic data base. The report stated that "It took one person six months to assemble and analyze additional data, and to learn how to use the model. Another six months were spent in calibration and long-record simulation." This time allocation applies to only a 28.5 square-mile basin. The quality of the final model is indicated by the average absolute monthly volume error of 32.1 and 28.1 percent for calibration and verification periods, respectively. Figure 4 shows a typical comparison of modeled and measured results. Peak flow rate absolute errors were 26 and 36 percent for calibration and verification periods, respectively. It was concluded that "Discharge frequency under changing urban conditions is a problem that could be handled by simpler, quicker, less costly approaches requiring much less data; e.g., design storms or several historical events used as input to a single-event model, or a continuous model with a less complex soil-moisture accounting algorithm."

In another study, HEC Technical Paper No. 59 (Abbott, 1978) compared six hydrologic models, plus two variants of one and a variant of another, in a preliminary evaluation of their relative capabilities, accuracy and ease of application on a 5.5 square-mile urban watershed near Oakland, California. Four continuous simulation models were tested: Storage Treatment Overflow Runoff Model (STORM), Hydrocomp Simulation Program (HSP), Streamflow Synthesis and Reservoir Regulation (SSARR), and Continuous Flood Hydrographs (HEC-IC). Single-storm event comparisons were made using STORM, HSP, SSARR, Storm Water Management Model (SWMM), Massachusetts Institute of Technology Catchment Model (MITCAT) and the HEC-1 unit hydrograph model (single area analysis). Each model was calibrated with the first 40 percent of a 42 month record, and the resulting calibration coefficients were used in simulating the remaining record. The study results showed that the more complex models did not produce better results in developing watershed runoff quantities than the simple models for this test watershed (see Fig. 5).

In the absence of more encouraging results in the use of complex hydrology models, the widespread use and continued acceptance of simpler rainfall-runoff models such as unit hydrograph methods for the estimation of watershed runoff quantities is understandable. For a new rainfall-runoff modeling approach to achieve widespread acceptance, it must clearly demonstrate a superiority in performance. For example, Hall (1984) writes that some predetermined criterion of "goodness-of-fit" is typically used to assess a new model's capability in reproducing historic storm event runoff quantities. The



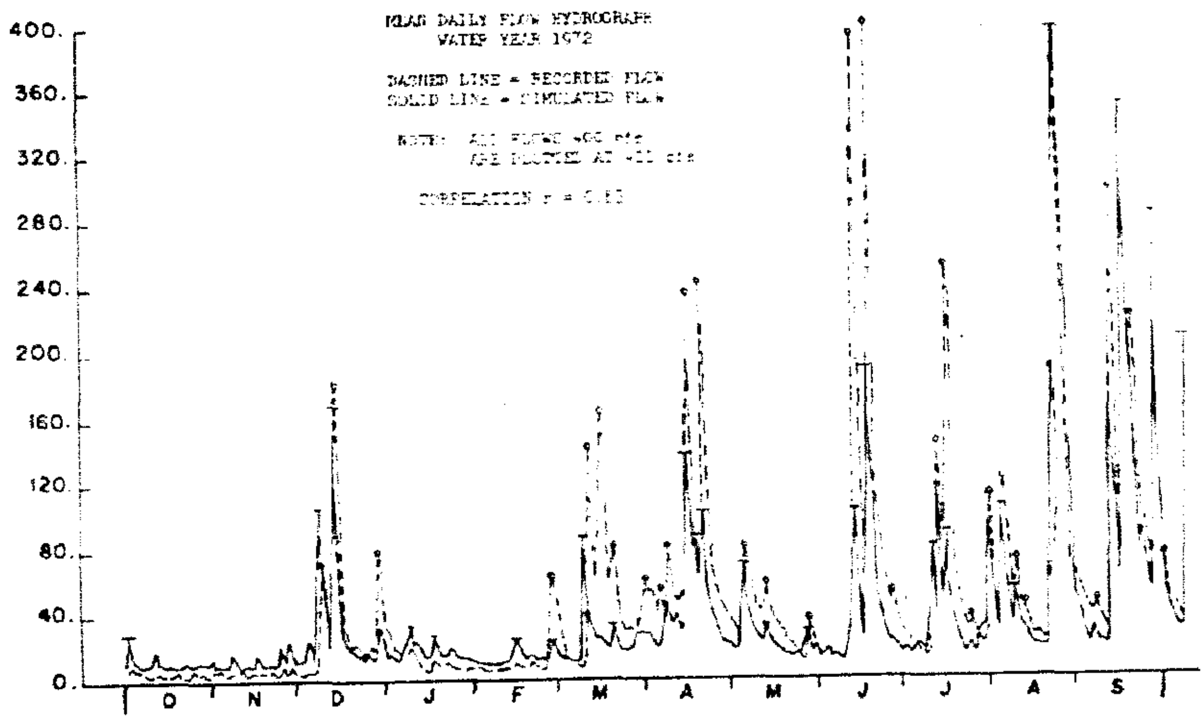
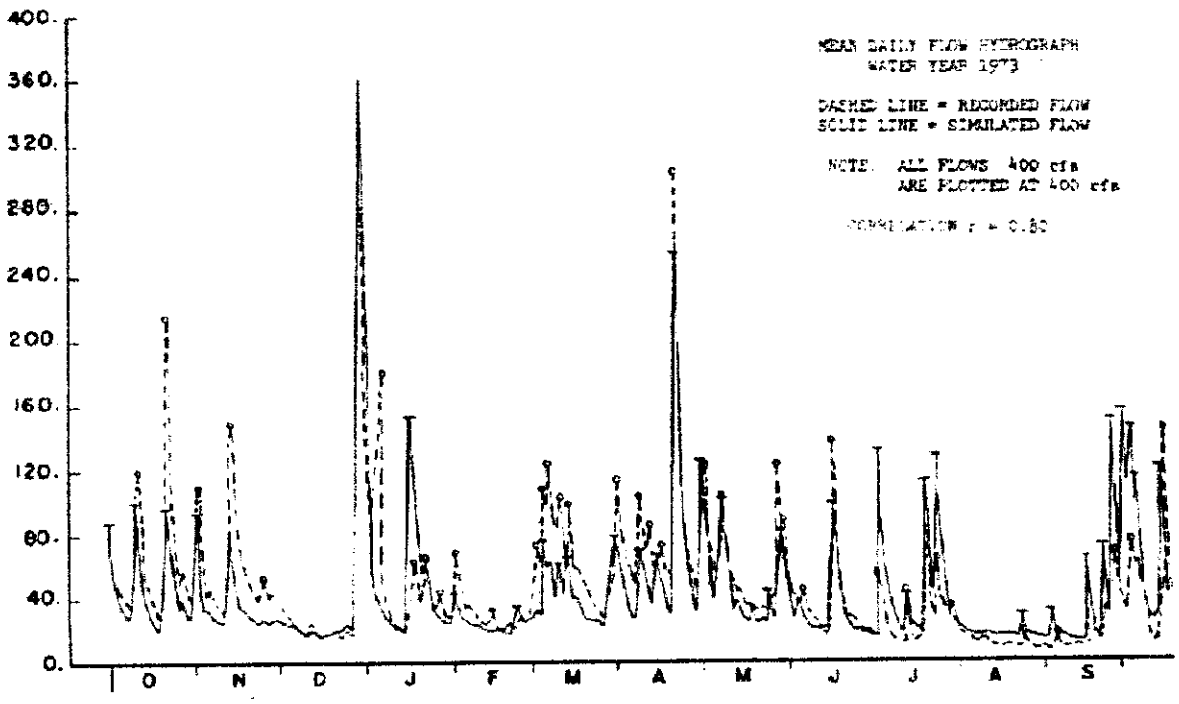


Figure 4a: Comparison of Hydrocomp HSP Model



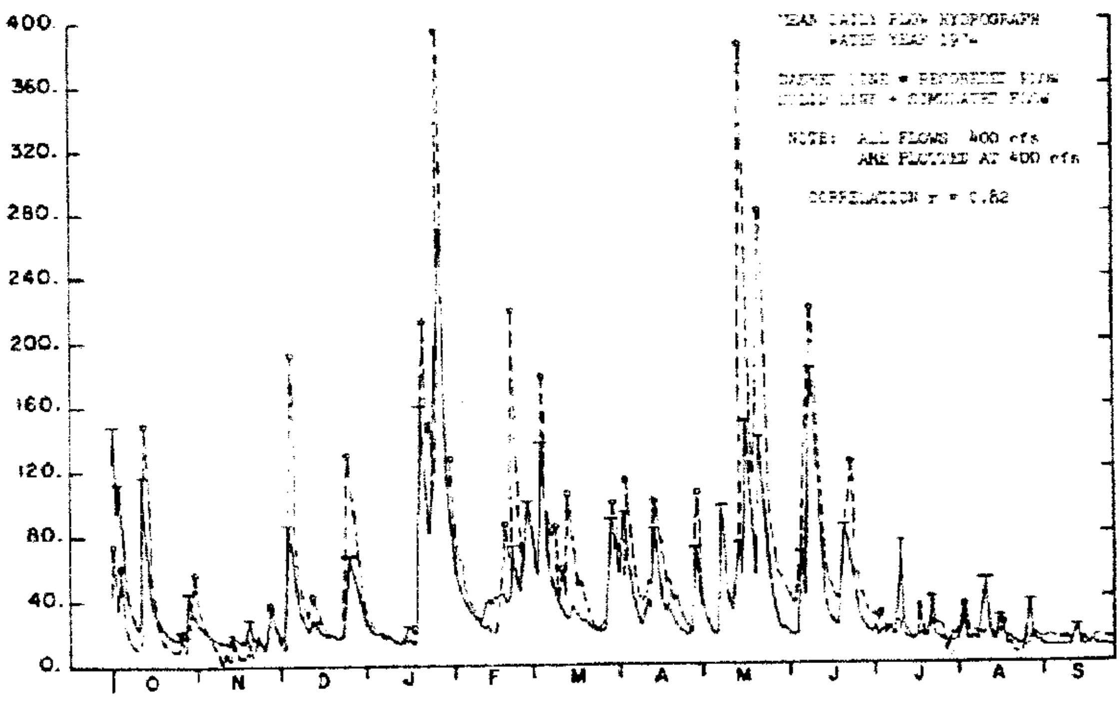


Figure 4b: Continuous Simulation Estimates to Stream Gauge Data

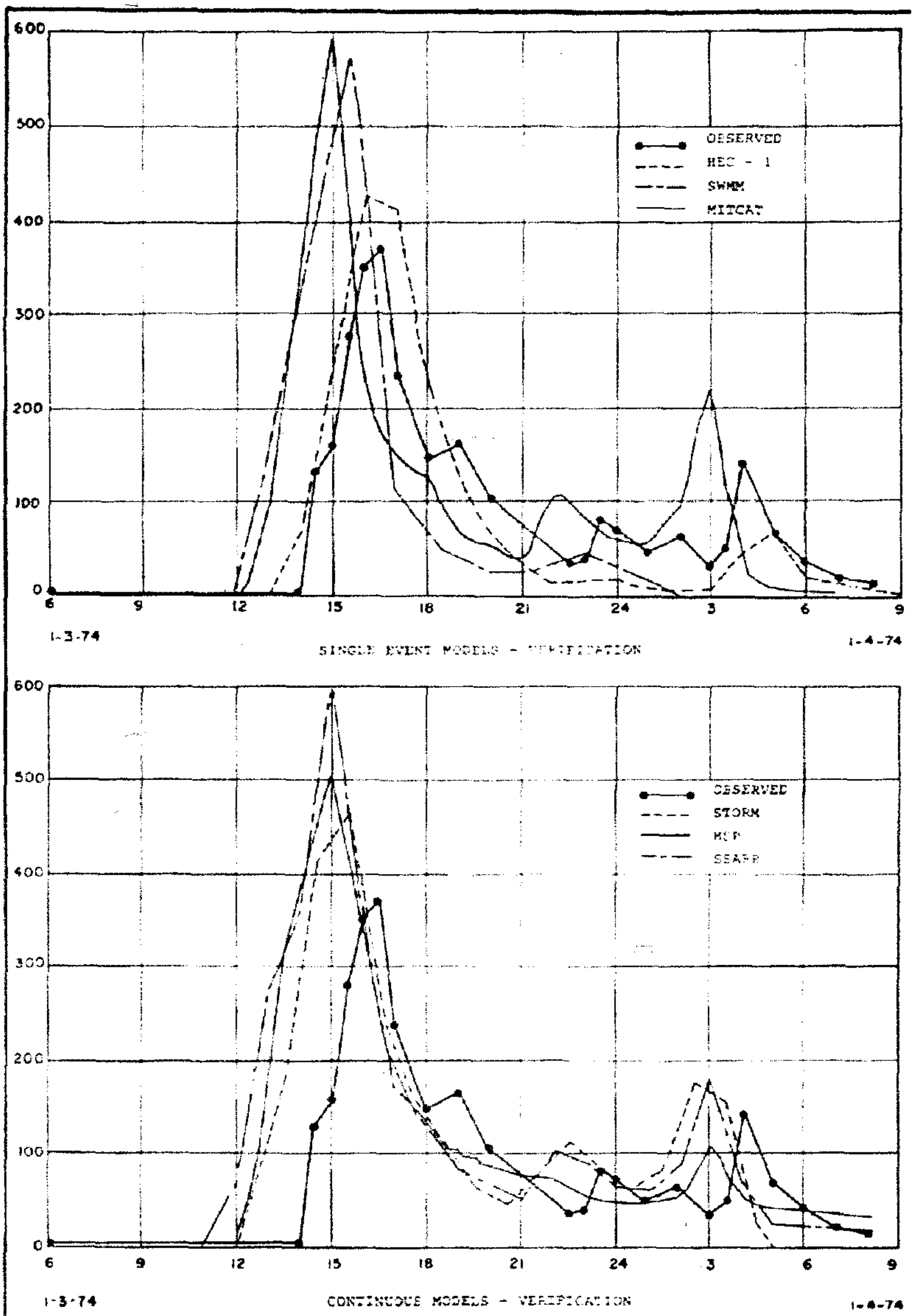
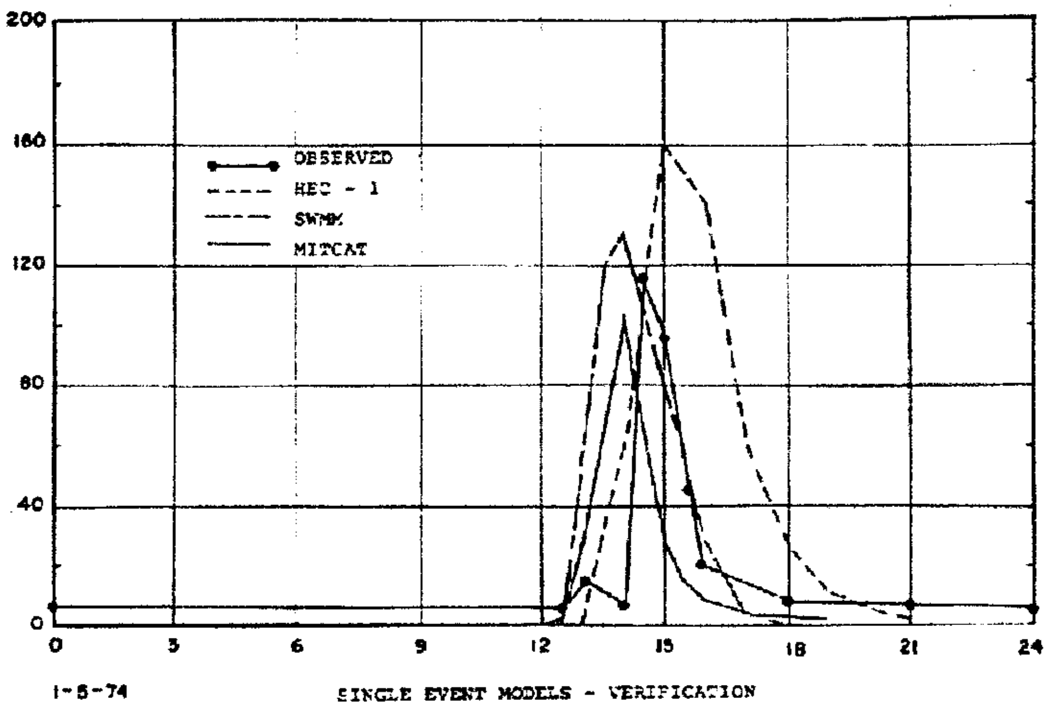

OBSERVED
HEC - 1
SWMM
MITCAT
1-3-74
1-4-74
SINGLE EVENT MODELS - VERIFICATION
OBSERVED
STORM
1-3-74
1-4-74
CONTINUOUS MODELS - VERIFICATION

Figure 5a


OBSERVED
HEC - 1
SWMM
MITCAT
200
160
120
80
40
0
0
3
6
9
12
15
18
21
24
1-5-74
SINGLE EVENT MODELS - VERIFICATION

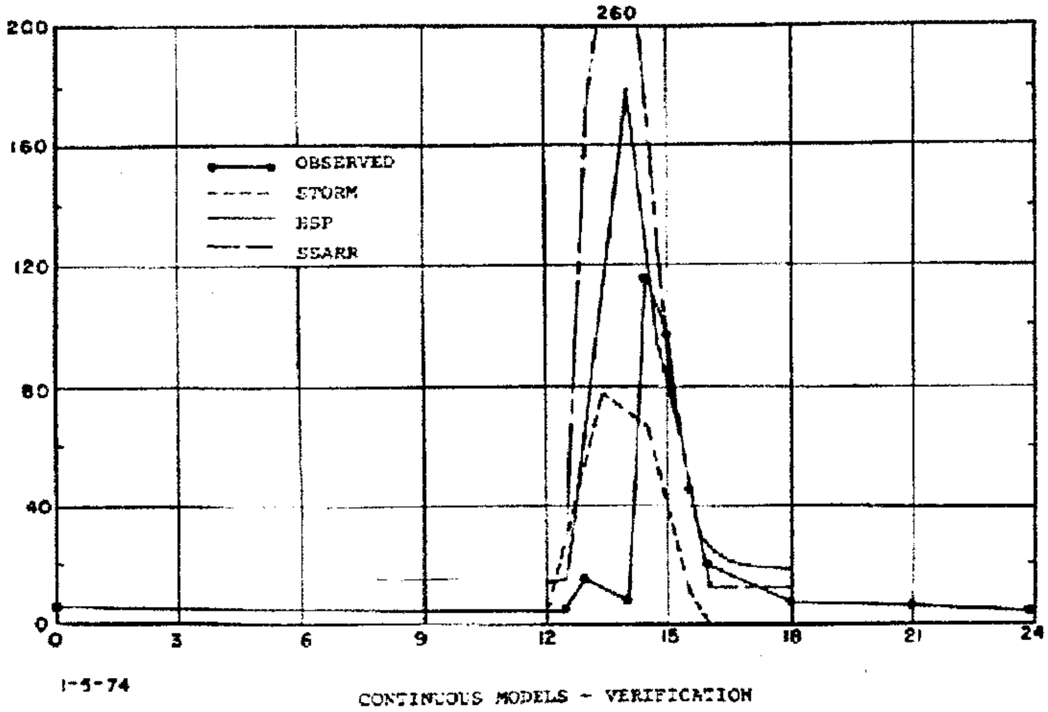

260
OBSERVED
STORM
ESP
SSARR
200
160
120
80
40
0
0
3
6
9
12
15
18
21
24
1-5-74
CONTINUOUS MODELS - VERIFICATION

Figure 5b

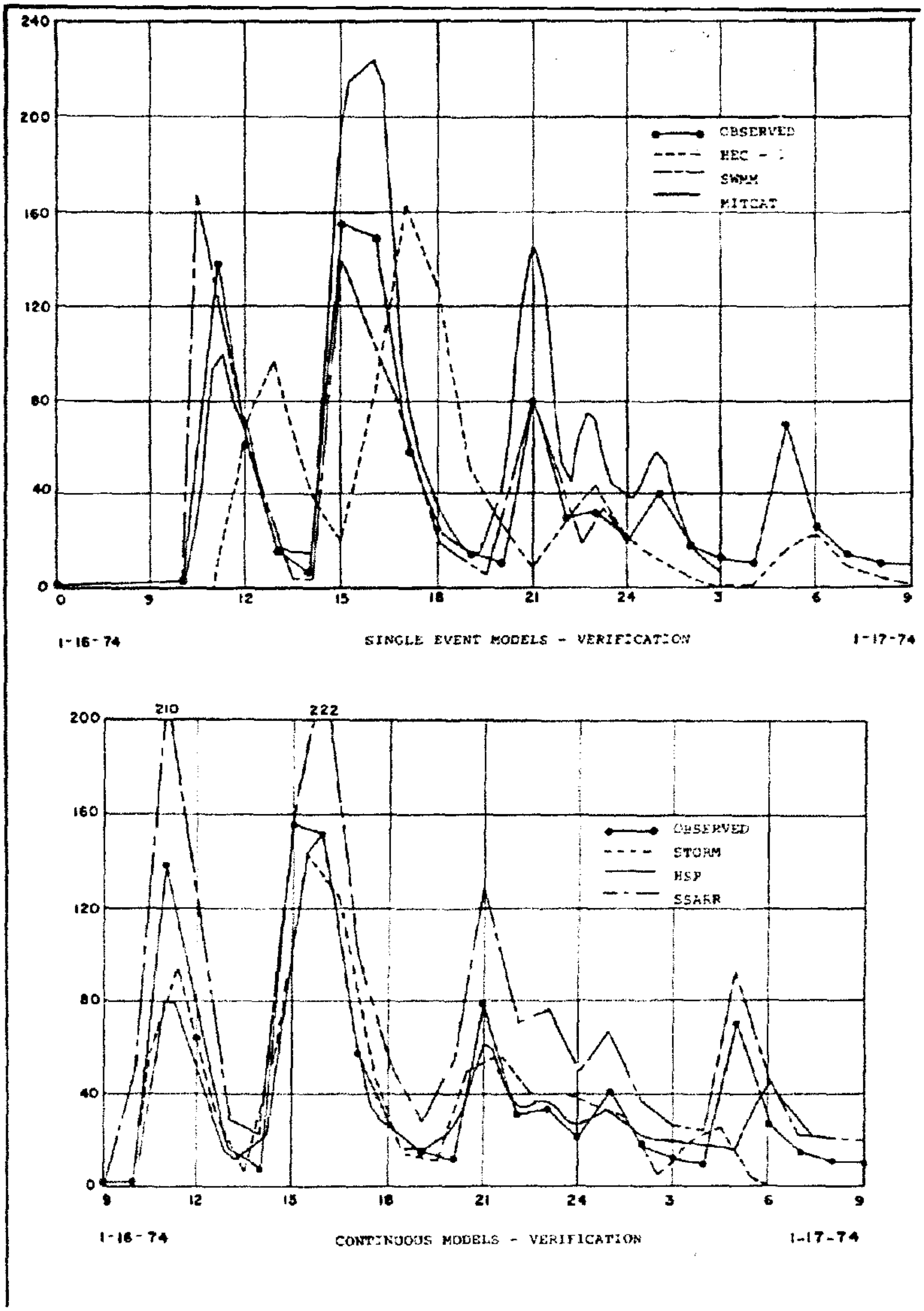

OBSERVED
HEC -
SWMM
MITCAT
1-16-74
SINGLE EVENT MODELS - VERIFICATION
1-17-74
210
222
OBSERVED
STORM
HSP
SSARR
1-16-74
CONTINUOUS MODELS - VERIFICATION
1-17-74

Figure 5c

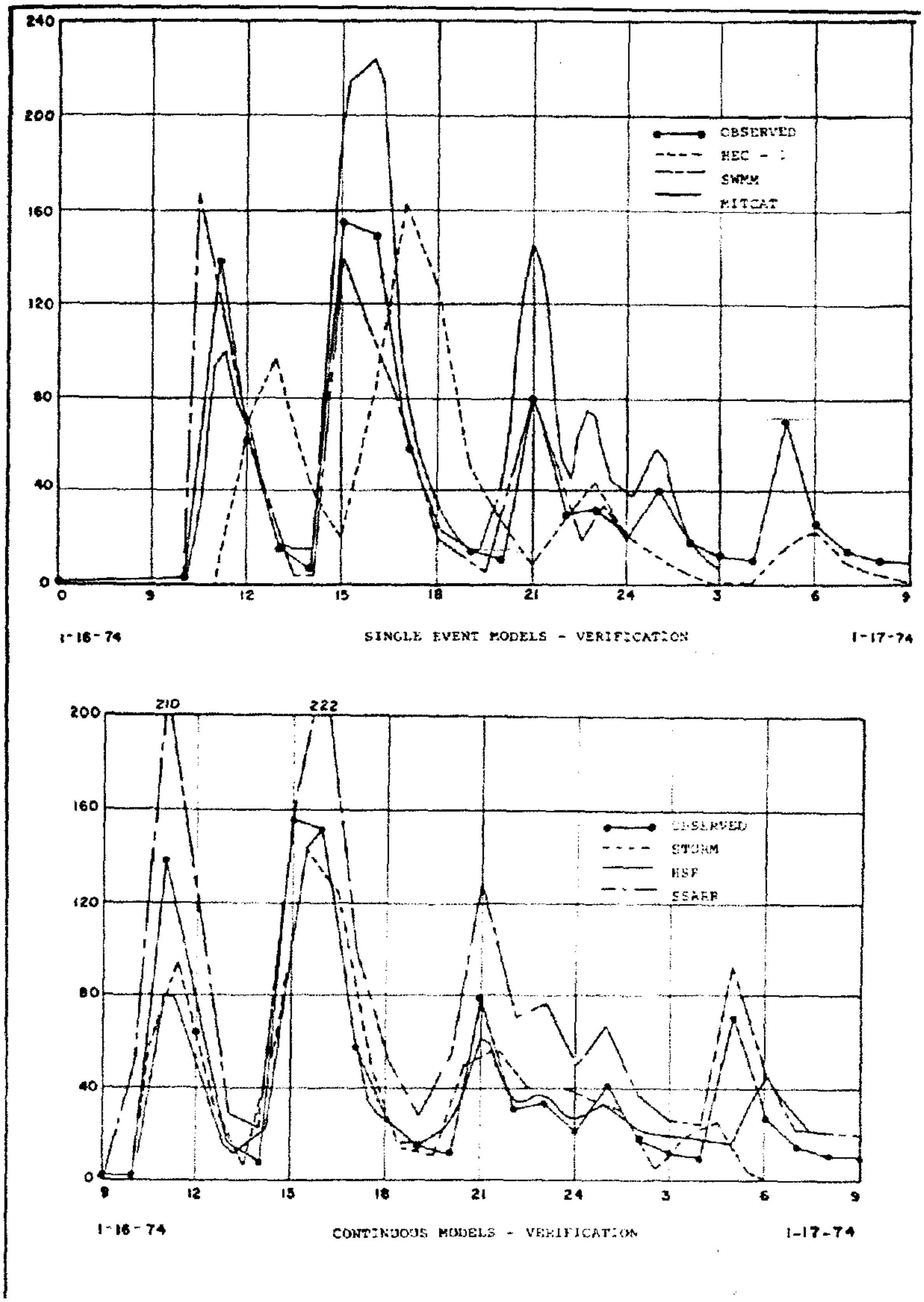


Figure 5a-d: Comparison of Calibrated Single Event and Continuous Simulation Modeling Estimates to Stream Gauge Data new model is first calibrated to observed rainfall-runoff data and then "verified" using storm events excluded from the calibration storm event data set. This type of split-sample testing (for example, TP-59, 1978; Loague and Freeze, 1985) has been found to be a standard in comparing rainfall-runoff model performance.

A second set of criteria must be evaluated when using a new rainfall-runoff model for design storm flood estimation. Model parameters must be correlated to watershed characteristics, or regional values of the parameters must be established. More specifically, the model parameters used as the dependent variables must provide a relationship between the return frequency of runoff and the return frequency of the input rainfall. Acceptance of any new modeling technique typically depends upon the models ease of use and reproducibility of the results by different engineers and hydrologists. Hall (1984) concludes that "until the additional steps required to develop a rainfall-runoff model into a flood estimation method are more widely appreciated, this apparent reluctance to accept innovation is liable to remain a feature of design practice."

The lack of success in concluding a purely deterministic rainfall-runoff modeling approach for developing watershed runoff quantities has motivated the proliferation of dozens of complex, conceptual or so-called physically-based models. However, based upon the available literature, the weight of evidence indicates that use of simpler models such as the well-known unit hydrograph approach will continue to be the most widely used modeling technique. It appears as though the simpler models are able to represent a considerable amount of the explainable phenomena that frequently occurs, and the improvement in modeling accuracy due to inclusion of additional complexity is oftentimes overwhelmed by the scale of uncertainty which cannot be reduced. In a study of stochastic hydrologic methods, Klemes and Bulu (1979) write that often modelers "sidestep the real problem of modeling – the problem of how well a model is likely to reflect the future events – and divert the user to a more tractable, though less useful, problem of how to construct a model that will reproduce the past events. In so doing they expect, and perhaps rightly so, that by the time the prospective modeler has dug himself out of the heaps of technicalities, he either will have forgotten what the true purpose of modeling is or will have invested so much effort into the modeling game that he would prefer to avoid questions about its relevance." According to Gburek (1971), "...a model system is merely a researcher's idea of how a physical system interacts and behaves, and in the case of watershed research, watershed models are usually extremely simplified mathematical descriptions of a complex situation...until each internal submodel of the overall model can be independently verified, the model remains strictly a hypothesis with respect to its internal locations and transformations...".

The current thrust in development of rainfall-runoff models is towards being physically based in that they model all the several components of the hydrologic cycle in rainfall-runoff processes. However the resulting products "...are simplified nonlinear, lumped parameter, time-invariant, discontinuous representations of a complex nonlinear, distributed parameter, time-variant and continuous system" (Sorooshian and Gupta, 1983). The use of a lumped parameter approach means that a characteristic or representative value of a parameter is assumed to apply for the entire watershed, for each parameter used in the model. The invariant parameter assumption assumes that all parameters are constant with respect to seasonal moisture changes. Rain gauge data are also lumped by some selected procedure which ignores the time and spatial variations of rainfall over the watershed, and between storm events. Watt and Kidd (1975) write that the differences between physically based and so-called "black-box" models, (e.g., unit hydrograph models), become less obvious when applied to a field situation. The authors conclude that the considerations of whether the model is physically based or is a black box model "should carry very little weight in the selection process."

Another major issue involving use of rainfall-runoff models is that each of these models requires a calibration of the model parameters be performed in order to obtain an optimum parameter set. However, currently there is no proven technique to obtain this true optimum parameter set.

A brief summary of the success and failures in calibration of model parameters is contained in Sorooshian and Gupta (1983) who write

> "In a recent paper, Alley et al. (1980) stated that 'many of these models have been developed as intellectual exercises rather than useful tools for practicing engineers'. They stressed the need for a balance between (1) processes and (2) the operational characteristics of the model affecting its utility for practical applications. Moore and Clarke (1981) expressed a similar concern by stating that 'it is no exaggeration to say that the present state of rainfall-runoff modeling is extremely fragmented'. Among the reasons they provided in support of the above statement are (1) the difficulty in the selection (i.e., among the many models available) of the 'right model' by a potential user and (2) the difficulty encountered in the calibration of the selected model, using an 'automatic' approach. With respect to the latter difficulty they reference the work of Johnston and Pilgrim (1976) and Pickup (1977) with the Boughton model. The most important conclusion of the work of Johnston and Pilgrim was their inability, in over two years of full-time effort, to find a 'true optimum' parameter set for a nine-parameter version of the Boughton model on the Lidsdale 2 catchment in Australia. Perhaps more disturbing is the fact that even under ideal conditions (created by assuming a perfect set of parameters and using synthetic data), Pickup (1977) was unable (using an automatic approach) to obtain the 'true' values of the Boughton model's parameters. Worth mentioning is the fact that Ibbitt (1970), working with a version of the Stanford watershed model, experienced the same difficulty."

The study of Johnston and Pilgrim (1976) highlighted the complexities associated to determining the optimum parameter set for a conceptual model, and although the Boughton model was used, it was concluded that "most of the findings are applicable to all rainfall-runoff models." Their study identified nine levels of difficulty in optimizing a parameter set, most of which are related to parameter interdependence and the use of a specific objective function to optimize the parameters. They conclude that "until more confidence can be placed in the derivation of truly optimum values, some doubt must remain on the potential usefulness of rainfall-runoff models." When attempting to calibrate a simulation model to model-produced runoff data, Gupta and Sorooshian (1983) reported that "even when calibrated under ideal conditions, it is often impossible to obtain unique estimates for the parameters."

In another examination of the 13-parameter Boughton model, Mein and Brown (1978) examine the conceptual rainfall-runoff model's sensitivity to variations in each parameter of the 'optimized' parameter set. They conclude that "relationships derived between any given parameter value and measurable watershed characteristics would be imprecise, i.e., they would have wide confidence limits" and that "one could not be confident therefore in changing a particular parameter value of this model and then claiming that this alteration represented the effect of some proposed land use change. On the other hand, the model performed quite well in predicting flows with these insensitive parameters, showing that individual parameter precision is not a prerequisite to satisfactory output performance."

Dawdy and Bergmann (1969) identify two categories of error which impact rainfall-runoff models, namely, errors in the estimation of an optimum parameter set and errors resulting due to the unknown variability and intensity of rainfall and storm volume over the watershed. The second error category "places a limit of accuracy upon simulation results," even given the true long-term parameter set. The study concluded that for the test 9.7 square-mile California watershed, using data from a single rain gauge whose data had been adjusted to represent mean basin conditions, the prediction of flood peaks could not be made better than about 20 to 25 percent using a rainfall-runoff simulation model.

Ideally, a dense network of rain gauges within the watershed should be used to determine the spatial and temporal variation in storm rainfalls for each storm event. However, usually only one or two gauges are available, and often not within the watershed. "Even if measurements from a single gauge may be assumed to be representative of overall basin precipitation in an expected value sense, other statistical properties of point rainfall, mainly variability, will differ considerably from the corresponding properties of average basin rainfall. The result can be serious errors in runoff prediction and large biases in parameter estimates obtained by calibration of the model" (Troutman, 1982).

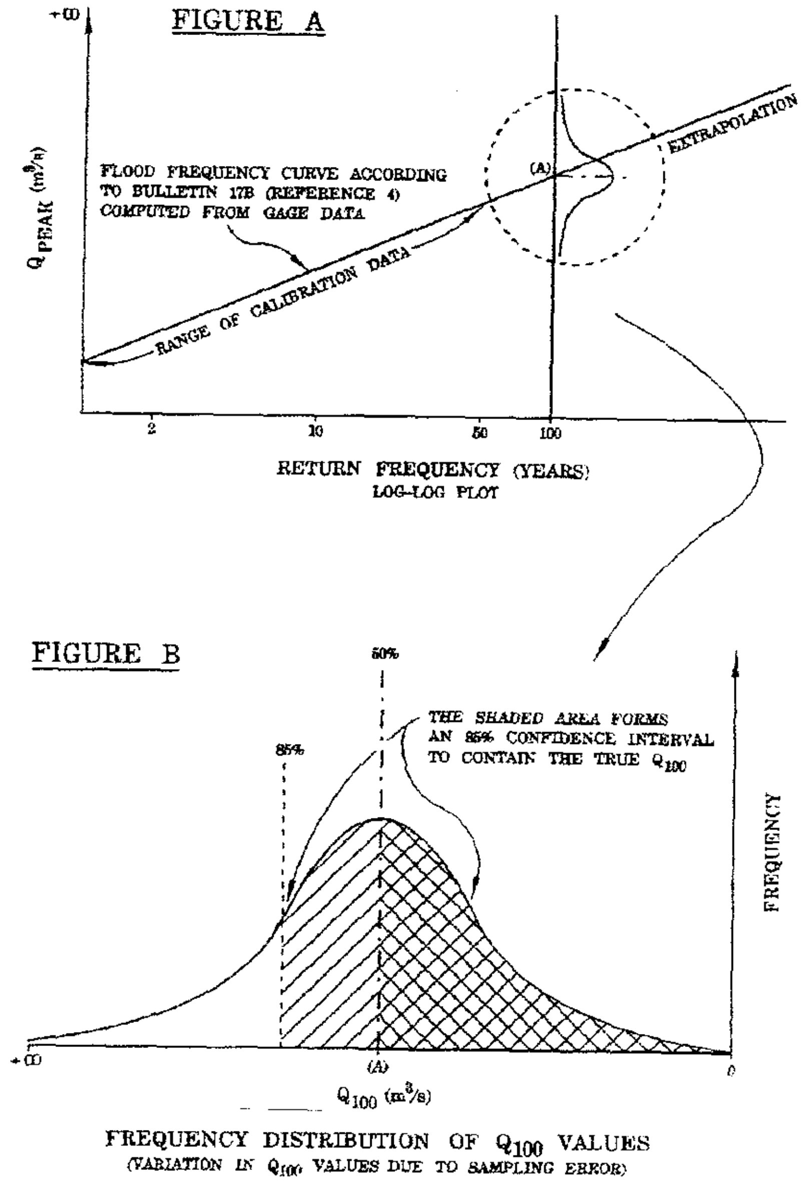
Indeed, rainfall measurement errors at the rain gauges themselves provide a source of concern (see for example, Kelway, 1975). "For single rainfall events, where the totally catch exceeded 12mm (0.5 inch), the error ranged between 0 and 75 percent, depending on wind characteristics during the storm," (Neff, 1977).

Another source of difficulty in the determination of the true optimum parameter set is the optimization procedure used during the calibration process, that is, the so-called objective function which is to be minimized. "The choice of the set of data and of the objective function to be used for any given model is a subjective decision which influences the values of the model parameters and the performance of the model," (Diskin and Simon, 1977).

Pilgrim (1986) writes that "Another approach uses a watershed model to simulate either a long flow record from continuously recorded rainfall, or a series of historical floods from the rainfall recorded in the major storms on the basin. While they are attractive theoretically, none of these approaches is used widely at present, and it is unlikely that any will make serious inroads on the use of a single design flood in the foreseeable future."

Pilgrim notes that "There has been a tendency for researchers to develop complex models of what they assume or imagine happens on real watersheds based on limited data. The enshrinement of procedures in sophisticated models may then lead to general acceptance that nature does actually behave in the assumed manner."

ISSUE: Flood Frequency Curves -- do flood frequency curves give the "true" results?



ORANGE COUNTY
HYDROLOGY MANUAL

etric

ADDENDUM NO. 1
DEFINITION SKETCHES FOR 85% AND 50% CONFIDENCE INTERVALS

ISSUE: Debris, Sediment, Fires -- can other effects result in exceeding the design flow rate?

FOREARMING FOR LITIGATION OUTLINE

I. UNDERSTANDING COMMON LEGAL PROCESS PITFALLS.

- Underdesign (quality vs. risk)
- Overdesign (defensibility vs. cost)
- Focus on the entitlement process (misunderstanding who sets the standards)
- Reasonableness and foreseeability (the threat of hindsight)

II. BUILDING A LEGALLY DEFENSIBLE FILE

- Identifying the legally significant issues
- Documenting the decision making process
- Avoiding unfairly damaging documentation