

SmartFlood 2.0 Demonstration

Peerapong Ekkawong

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Harold Vance Department of

PETROLEUM ENGINEERING
TEXAS A & M UNIVERSITY

Model Calibration and Efficient Reservoir Imaging: MCERI

Contents

- Introduction
- Workflow
- Result: maximize flood efficiency
- Result: production acceleration
- Other applications
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What is SmartFlood?

- Smartflood can optimize production/injection rates by equalizing the arrival time of the waterfront at all producers within selected sub-regions of a waterflood project under operational and facility related constraints.
- Software designed based on streamline-based approach proposed by Ahmed Alhuthali (SPE 102478) to maximize waterflood sweep efficiency.
- Major advantage of this approach is the analytical computation of sensitivities of the front arrival times and gradient and Hessian of the objective function

SmartFlood 2.0

A1	B	C	D
	OPTCONTROL	ACTUAL	REMARKS
1	OPTCONTROL	DEFAULT	
2	SimType	ECLIPSE	Simulator Type = ECLIPSE or FRONTRIM. The simulation deck should have keywords corresponding to simulator type.
3	SimVersion	v2010.2	Simulator version = v2010.2 or any other available on machine from which the summary and restart files have been generated.
4	ITpa	1	Type of optimization = 1 (optimize both injection and production rate) or 0 (optimize only production rate).
5	Risk	0	Risk coefficient for multiple realization optimization.
6	ECRTType	WATER	Injection Scheme = WATER or WATER&GAS or GAS or WAG
7	NormWt		Norm weight for production acceleration.
8	TStepType	TSTEP	Simulator timestep type = TSTEP (days) or DATES.
9	OptStartDate	1-Jan-10	Date for start of optimization. Required for NPV calculation.
10	OptStartStep	0	Step index where optimization start in field life (non-optimized production prior to that) = 0 (for no production history) or RESTART index for last step in history.
11	Step	0	Step index within optimization period = 0 for first step. The current timestep index is thus (OptStartstep + Step + 1) from START date in simulation deck.
12	Restart	NO	Restart SmartFlood from the last point it was killed or crashed? YES or NO. Results from each iteration for current timestep are saved to allow for flexible restart.
13	MaxIter	10	Maximum number of iterations per optimization timestep. After these many iterations, the rates corresponding to minimum objective function will be considered as Allow different start production/injection rates for different timesteps = YES or NO (rates from STARTPROD\STARTIN\1\STARTGIN\1 considered as base rates).
14	MultipleStart	NO	Use optimized production/injection rates for a timestep as starting rates for next timestep = YES or NO.
15	UseOptRate	NO	Index for start realization = 1.
16	StartRe	1	Index for end realization = 1 (for single realization optimization) or number of realizations considered for multiple realization optimization. All realizations from StartRe to index for realization to compute constraints = 1 (for single realization optimization) or index between StartRe and EndRe, both inclusive (for multiple realization).
17	EndRe	1	Number of streamlines generated by DESTINY for tracing when using ECLIPSE.
18	BaseRe	1	YES (Read specified injector grouping based on faults, well connectivity etc.) or NO (groups generated by SmartFlood based on sensitivities using 80% fastest file format for TOPSENS = FORMATTED or UNFORMATTED (Recommended)).
19	NumStream	1000	400
20	ReadWellGroup	YES	
21	FileFormat	UNFORMATTED	
22	MinProdRate	0	Min production rate for wells. Minimized during optimization. The maximum limit specified.
23	WeightWVCT	OFF	Penalize time-of-flight during optimization after gas breakthrough = ON or OFF.
24	WeightExp	0.5	Exponent used for penalizing well gas-oil ratio in equation (1-GOR/GORmax)/Exp.
25	WellWaterCut	0.98	Max allowable well gas-oil ratio for any voltage production rate.
26	WeightWGOR	OFF	Penalize time-of-flight during optimization after polymer breakthrough = ON or OFF.
27	WeightExpGOR	1	Exponent used for penalizing well gas-oil ratio in equation (1-GOR/GORmax)/Exp.
28	WGORConst1	1000	Max allowable well gas-oil ratio for rate greater than minimum voltage production rate.
29	WGORConst2	1000	Max allowable well gas-oil ratio for any voltage production rate.
30	WeightWPC	OFF	Penalize time-of-flight during optimization after polymer breakthrough = ON or OFF.
31	WeightExpWPC	1	Exponent used for penalizing well polymer production concentration in equation (1-HCPC/HPCmax)/Exp.
32	WPCConst1	0.035	Max allowable well polymer production concentration for rate greater than minimum voltage production rate.
33	WPCConst2	0.035	Max allowable well polymer production concentration for any voltage production rate.
34	ICV	NO	YES (if ICV present in field) or NO. If ICVs are present, each ICV should be treated as a separate well in simulation deck. The well identifiers for ICVs and rate/BHP.
35	BHPmargin	10	If well BHP lies in this range (+/-) of specified BHP constraint, maximum rates for optimization are forced to be equal to actual rates, to prevent well switching.
36	MaxFieldProd	NO	Force optimized field production to the specified maximum field production by treating it as Equality constraint = YES or NO.
37	MaxFieldInjEq	NO	Force optimized field injection to the specified maximum field injection by treating it as Equality constraint = YES or NO.
38	FieldProdEqInj	NO	Force optimized field production and injection on voltage balance which need not be max field rates, by treating them as Equality constraint = YES or NO.
39	Stngnt_Constraints	NO	YES (honor stringent constraints in GDP and break optimization) or NO.
40	Keyword1	GASOLWATPHASE	OLWATPHASE
41	Keyword2	GASOLWATPHASE	OLWATPHASE
42	Coarsen	NO	Phases present during simulation (for DESTINY) = OIL or GAS or WATER or any combination of these.
43	Coarsen	NO	Phases to be traced to generate .SLM files (for DESTINY) = OIL or GAS or WATER or any combination of these.
44	Coarsen	NO	COARSEN keyword present in simulation deck for runtime upscaling = YES or NO.
45	Frontsim	NO	YES (use FRONTRIM to run base, then use eclipse) or NO.
46	Datam	YES	YES (save additional files like .dat, .WDATA, .dat, .sum, .dat etc for debugging) or NO (delete those files).
47	Datam	YES	
48	Datam	YES	

Excel Input

SmartFlood v2.0
(Optimal Rate Management)

INPUT FILE :

LOAD FILE **RUN OPTIMIZATION**

MCERI Model Calibration and Efficient Reservoir Imaging (MCERI)
PETROLEUM ENGINEERING DEPARTMENT OF PETROLEUM ENGINEERING | TEXAS A&M UNIVERSITY

Software requirement

- MCRinstaller
- EXCEL input sheet
- ECLIPSE – modified data deck

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SmartFlood Workflow

Read EXCEL INPUT file

Run Simulator

Run DESTINY for streamline tracing

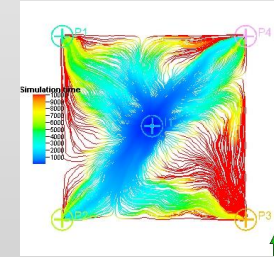
Calculate sensitivities

Update production/injection rate

Output optimized
rate files

ECLIPSE

ECLIPSE* reservoir simulation software



$$\frac{\delta \tau_i}{\delta q_i}$$

$$q_i = q_i + \Delta q$$

Objective Function Formulation

Min

$$p(\mathbf{q}) = \sum_{i=1}^{N_{\text{prod}}} (t_d(\mathbf{q}) - t_i(\mathbf{q}))^2 + \eta \sum_{i=1}^{N_{\text{prod}}} (t_i(\mathbf{q}))^2$$

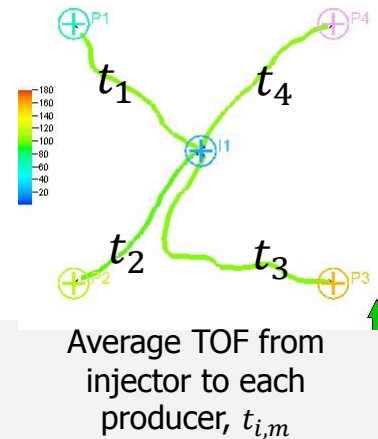
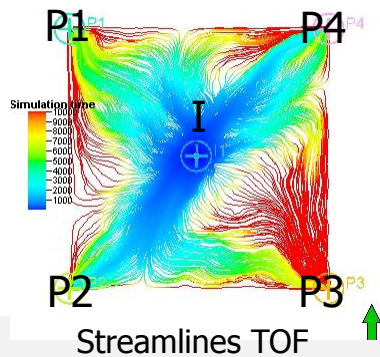
Average arrival time
Arrival time of producer i
Norm weight

Maximize flood efficiency

To minimize this term, variation of arrival time should be reduced which comes from rate allocation

Acceleration

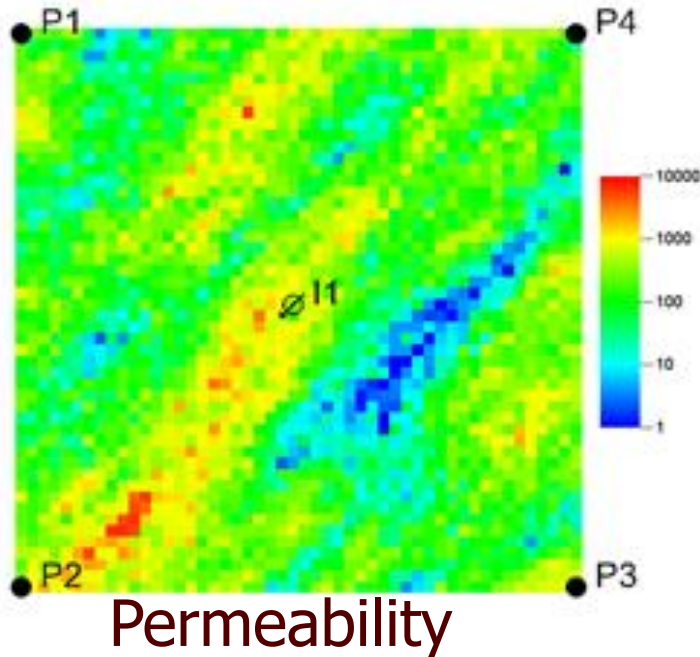
To minimize this term, arrival time should be reduced which comes from produce with higher rate



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Synthetic 2D Case



2D example case

- 50x50 grid
- Spatial Permeability

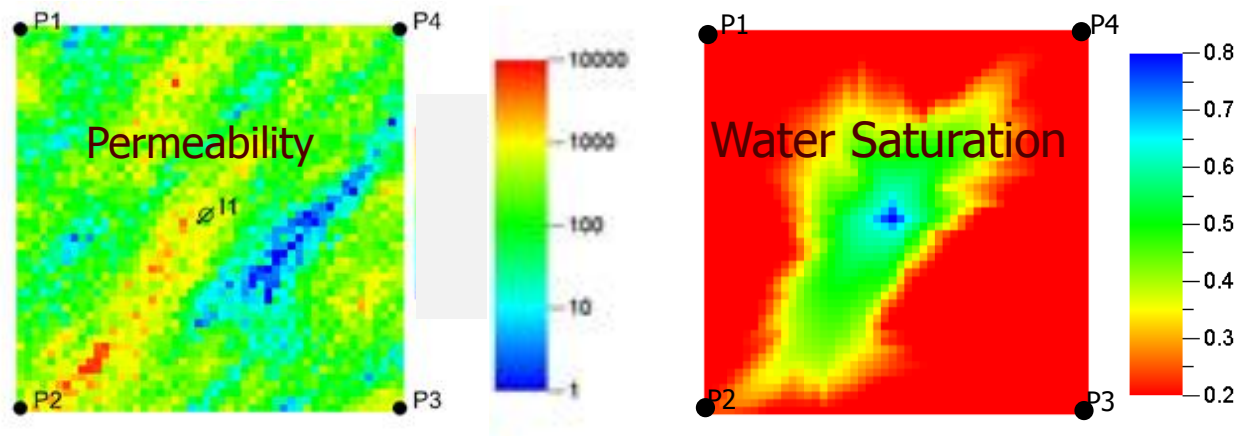
Constraints:

- Field water injection 400 RB/D
- Well production rate ≤ 300 RB/D for each well
- Production BHP ≥ 1000 psi
- Voidage balance

Want to optimize rate from 4 producers

Compare with base case of 100 RB/D each well

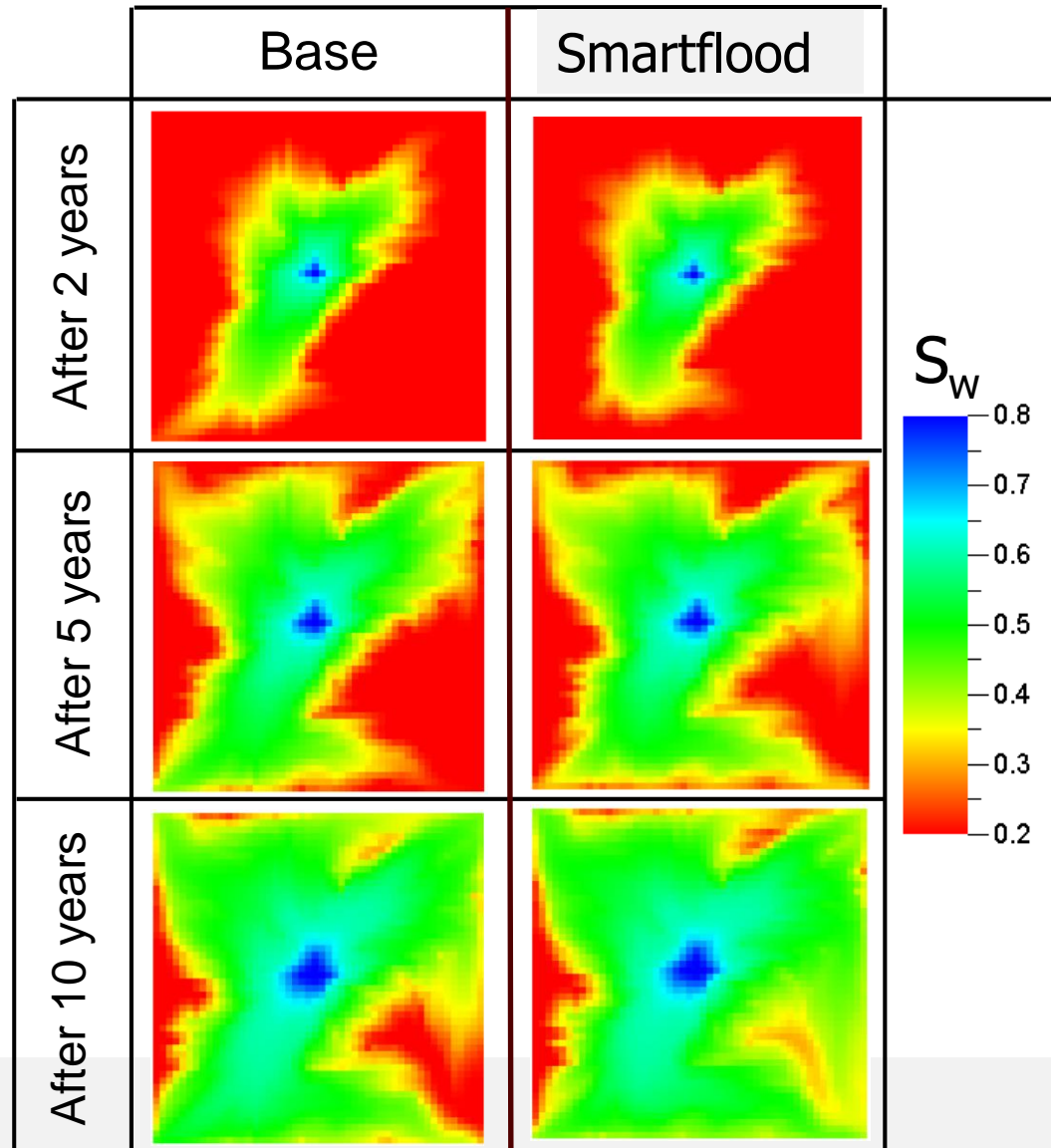
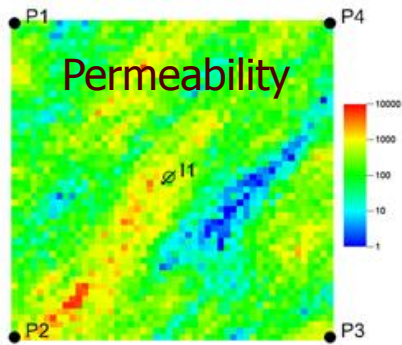
Result from Base Case (without rate optimization)



Well P2 and P4 have high permeability streak -> water breakthrough very fast

Smartflood will search for rates that equalize water breakthrough from all producers

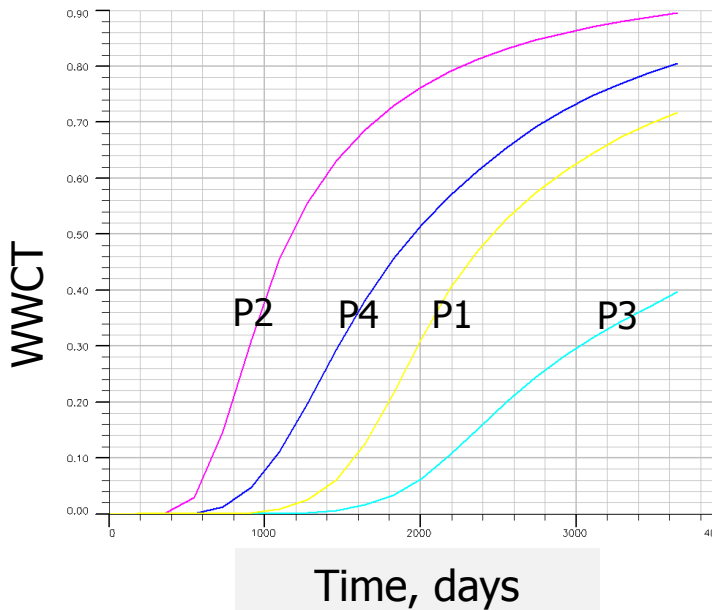
Results after optimization



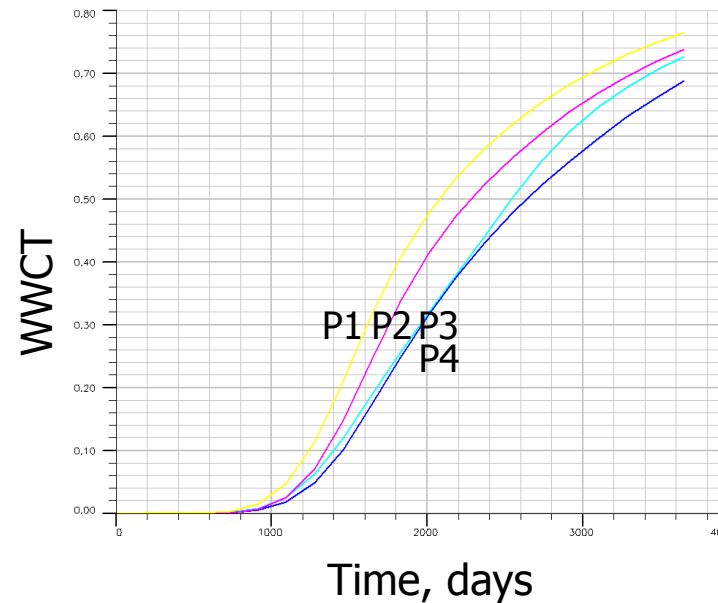
More uniform waterfront movement after optimization

Watercut Comparison

Base case



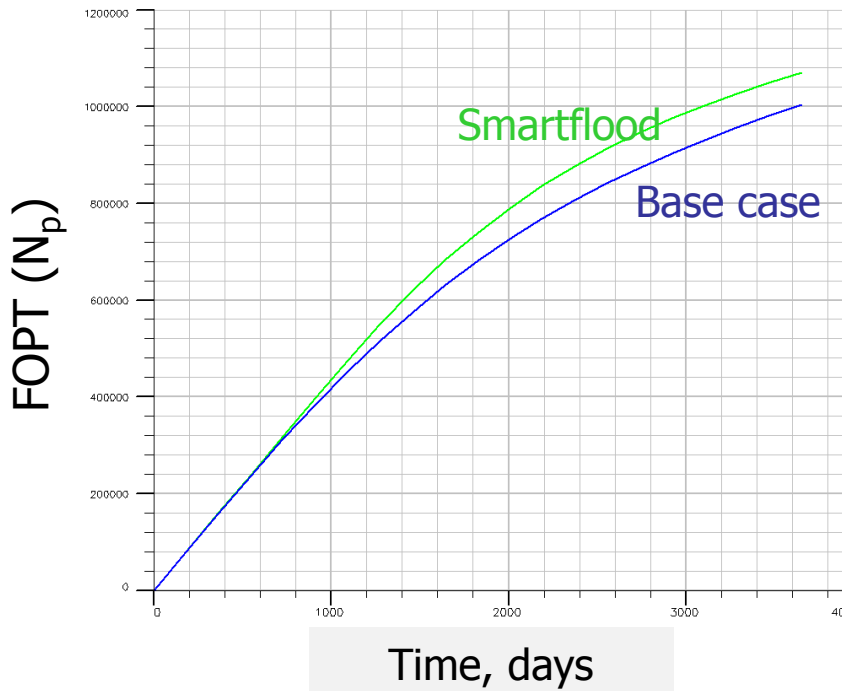
Maximum sweep efficiency



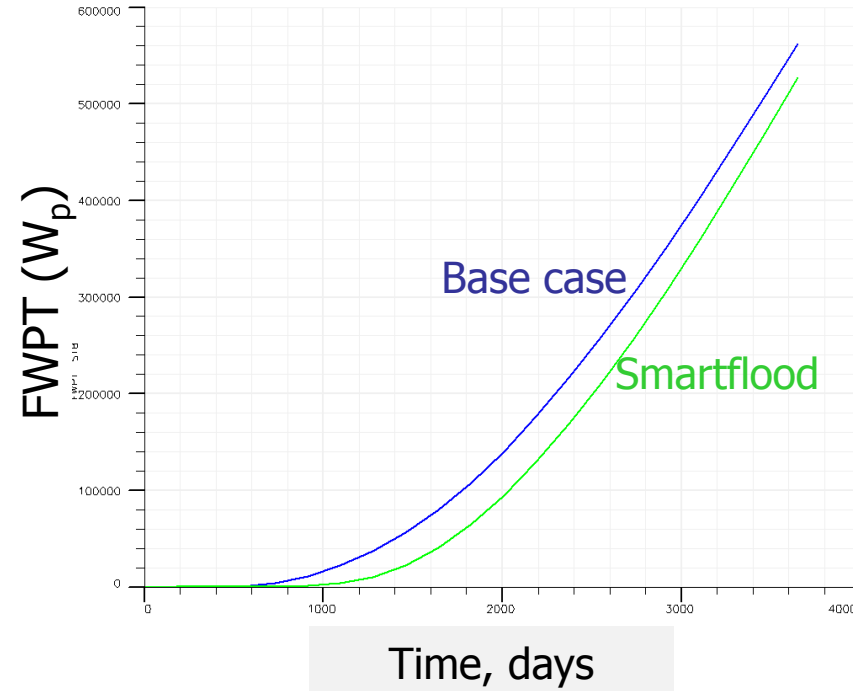
More uniform water breakthrough after optimization

Cumulative Production Comparison

Cumulative oil production



Cumulative water production

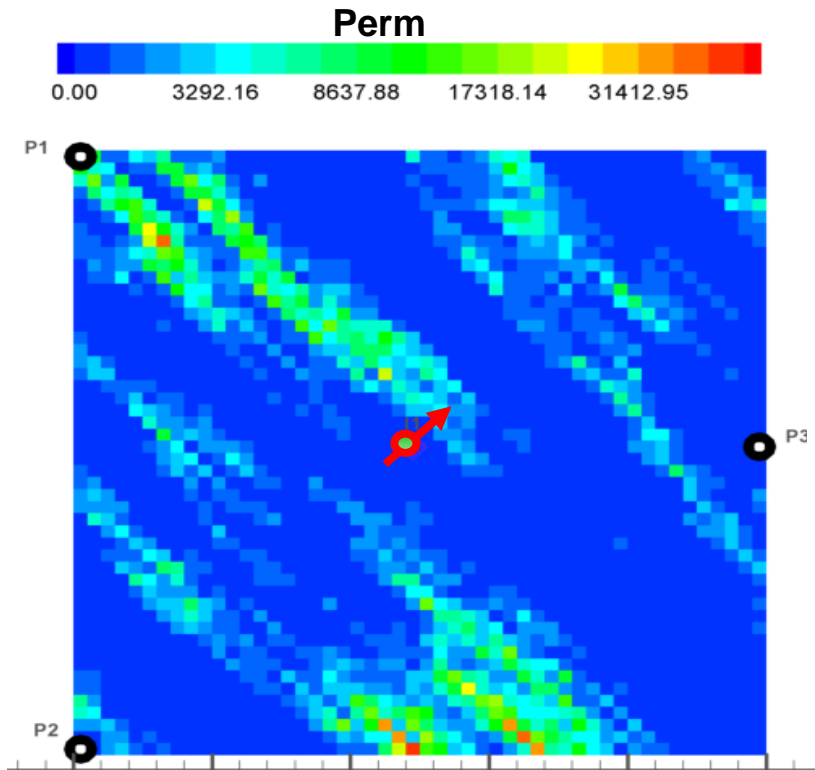


More oil production and less water production

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Illustration: Synthetic Field



NPV Optimization Using Sensitivities with
Numerical perturbation (45 min)

Vs.

Smartflood (2-3 min)

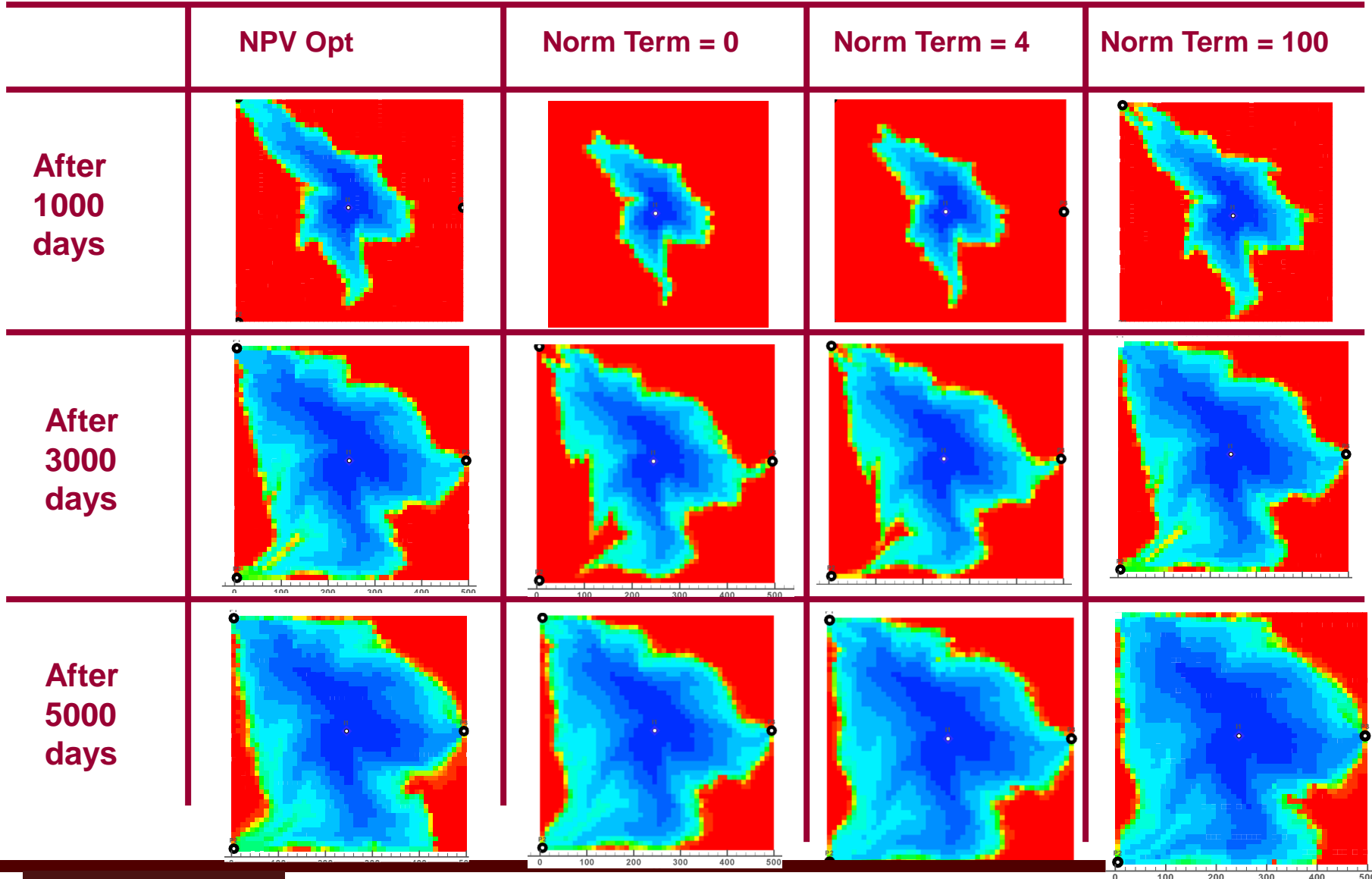
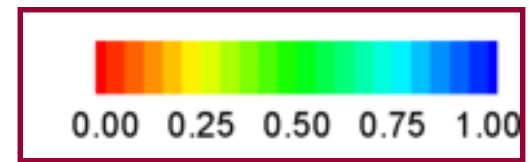
Total production time period = 5000 days. Time step for optimization = 1000 days

Specification for NPV:

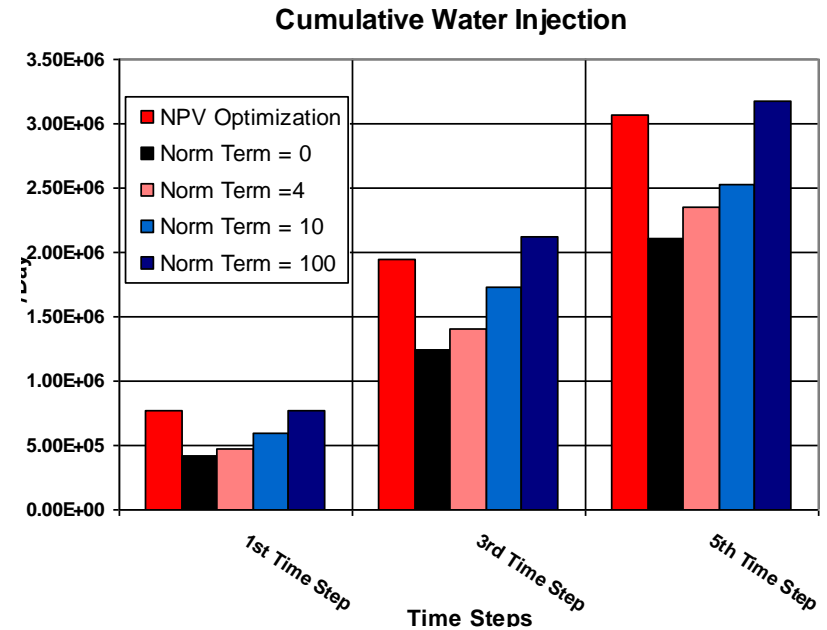
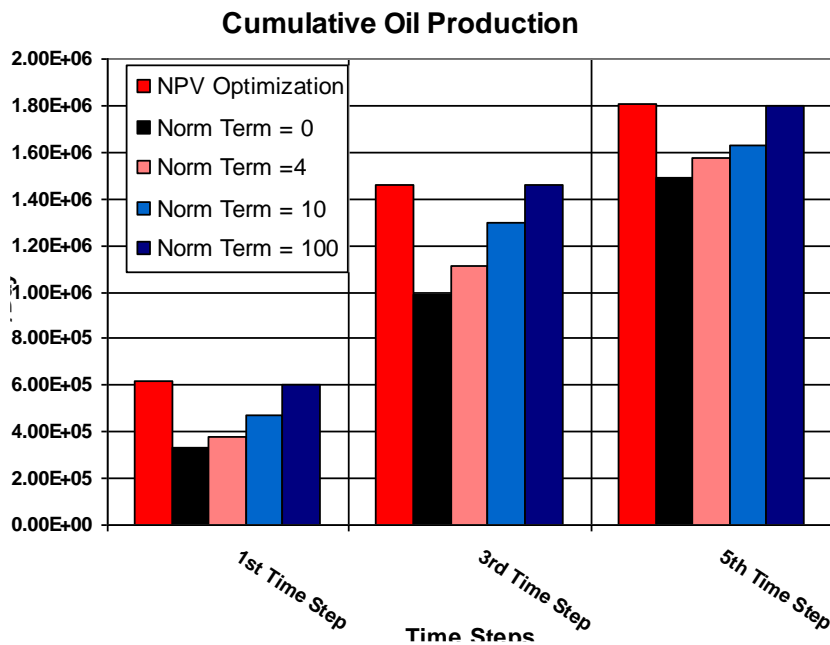
Discount rate = 10%, oil price = 50\$/bbl, water cost = 5\$/bbl

Total field rate \leq 800 rb /day, Ind. Well rate \leq 300 rb/day, voidage balance

Water Saturation Maps



Result of norm weight



More oil production can be produced by higher norm weight. The effect of increasing norm weight is similar to NPV optimization.

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Applications

Applications	SPE#
Optimal Waterflood Management Using Rate Control (Maximize sweep efficiency)	102478
Optimal Water Flood Management Under Geological Uncertainty Using Accelerated Production Strategy (Production acceleration by norm weight)	133882
Optimal Rate Control Under Geologic Uncertainty (Multiple realization)	113628
Field Applications of Waterflood Optimization via Optimal Rate Control With Smart Wells (ICV)	118948
Optimizing Polymerflood via Rate Control (EOR)	144833



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Thank you!

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